ASSESSMENT OF SOIL EROSION BASED ON SATELLITE REMOTE SENSING DATA

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Civil Engineering with Honours

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

Soil erosion is one of the significant issues in the river basins of Malaysia that will negatively result in sedimentation and decreased agricultural output. Klang River Basin is experiencing significant environmental changes due to extensive land use changes, economic growth, population growth, and uncontrolled urbanization. This research aims to assess the annual soil erosion in Klang River Basin using the Revised Universal Soil Loss Equation (RUSLE) model with the assistance of satellite remote sensing (RS) techniques and geographic information systems (GIS). Precipitation, wind velocity, temperature, and humidity are the meteorological and hydrological parameters that influence soil moisture and can contribute to soil erosion. The RUSLE model was implemented to estimate the annual soil erosion rates in Klang River Basin. Several factors were evaluated in the RUSLE model, which are rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and conservation practices (P). To increase the accuracy of soil erosion prediction, the RUSLE model was integrated with RS and GIS by incorporating spatially explicit datasets on rain gauge data, land use, soil type, and digital elevation model (DEM). The calculated values of the R, K, LS, C and P factors varied from 771.76 to 1165.43 MJ mm ha^{-1} h^{-1} yr^{-1}, 0.11 to 0.13 Mg h MJ^{-1} mm^{-1}, 0 to 40.8963, 0 to 1, and 0.1 to 1.0. The geographical distribution of annual soil erosion ranges from 0 to 300 tons ha^{-1} yr^{-1}. The values of potential soil erosion were divided into seven groups: very low, low, moderate, high, severe, extreme, and exceptional, with a numeric range of 50 tons ha^{-1} yr^{-1}. The research concluded that most of the study area in Klang River Basin had a very low risk of erosion, and every smaller location had a significant risk of erosion. Although the RUSLE model does not directly incorporate soil moisture as a factor, it can still influence soil erosion rates indirectly by affecting rainfall erosivity, soil erodibility, vegetation cover, etc. Therefore, it is crucial to consider all relevant factors, including soil moisture, to predict soil erosion rates accurately. The findings from this research can serve as essential information to aid in conservation management and land-use planning. Lastly, the methods employed in this research can facilitate the recognition of regions in the Klang River Basin that are prone to soil erosion.

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LIST OF SYMBOLS / ABBREVIATIONS

A	Average Annual Potential Soil Loss
C	Cover-Management Factor
CC	Correlation Coefficient
DEM	Digital Elevation Model
DID	Department of Irrigation and Drainage
ESRI	Environmental Systems Research Institute
FAO	Food and Agriculture Organization
f_{cl-si}	Factor for Soils with High Clay to Silt Ratios
f_{csand}	Factor for Soils with High Coarse-Sand Contents
f_{hisand}	Factor for Soils with Extremely High Sand Contents
f_{orgc}	Factor for Soils with High Organic Carbon Contents
GIS	Geographic Information System
GLDAS	Global Land Data Assimilation System
GPM-IMERG	Integrated Multi-satellite Retrievals for GPM
K	Soil Erodibility Factor
LS	Length and Steepness of Slope Factor
LULC	Land Use/Land Cover
m_c	% Clay Content
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, Version 2
m_s	% Sand Content
m_{silt}	% Silt Content
MUSLE	Modified Universal Soil Loss Equation
NASA	United States National Aeronautics and Space Administration
orgC	% Organic Carbon Content
P	Support Practice Factor
R	Rainfall Erosivity Factor
RS	Remote Sensing
RUSLE	Revised Universal Soil Loss Equation
SRTM	Shuttle Radar Topography Mission
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

In many parts of the world, soil erosion is thought to be the main factor causing ecological harm, water contamination, and land degradation. Major hydrological issues in the regions include soil erosion, sedimentation, and filling up of riverbed areas. Erosion is the geological process by which earth materials are eroded and transferred by natural force. Soil erosion can be caused by natural forces like wind and water or physical disturbance. Soil erosion is a hazard due to its long-term effects on reducing land productivity and threatening the sustainability of agriculture. Soil erosion will deteriorate the quality of the soil, air, and water. In general, soil erosion causes a net loss of soil, a deterioration in soil fertility, and sometimes the complete loss of soil covers by creating an imbalance in the rates at which the soils are formed (Vanwalleghem, 2017). The global carbon cycle and the mechanisms behind climate change are heavily impacted by soil erosion.

The world map showing the status of human-induced soil degradation takes into consideration topsoil loss and terrain distortion due to soil erosion. These soil erosions are caused by deforestation, vegetation or ground cover removal, and overgrazing in mountainous locations. The main factors contributing to land resource degradation are the shrinkage of pasture or forest areas, landslides, mudslides, soil loss from extremely steep slopes, and the collapse of man-made terraces. The long-term effects of soil erosion will cause a threat to the world's food security (Patil, et al., 2015). Apart from that, soil erosion harms the ecosystem by causing pollution, increased flooding, and sedimentation. In temperate and tropical climates, mild and frequent erosion events can have serious consequences. In almost every nation on Earth, erosion control is essential for practically every sort of land use. The influence of soil erosion on water quality becomes significant, especially when receiving runoff from soil surfaces. The relationship between sediment generation and soil erosion is close. Therefore, the most efficient strategy to reduce sediment production is to stabilise sediment sources through erosion management. For sustainable land use, soil and water resources must be preserved and used to their total capacity.

Malaysia, which is located in a tropical climate, is similarly affected by soil erosion. Due to economic growth, industrialisation, major migrations, and natural population growth, Malaysia has rapidly spread urbanisation. This unexpected expansion consumed a substantial amount of fertile land in the metropolitan environment and its surroundings (Mohammed, et al, 2015). In Malaysia, economic development, urbanisation, and population growth have quickened soil erosion, river sedimentation, and declines in river water quality. It is projected that considerable soil erosion is filling the riverbeds in numerous river basins in Malaysia, which is a significant cause of frequent flooding (Hussein and Shahid, 2017). Assessing land soil erosion is frequently challenging due to the complex interactions of many different characteristics, such as terrain, human activity, and climate. Soil loss is also influenced by political aspects as well as social, economic, and biophysical variables. One of the worst natural disasters that deplete watersheds of their fertile and well-organized soil is undoubtedly water-soil erosion. In hilly terrain that has been transformed by human activity, accelerated surface erosion and episodic landslides are frequent, which contribute to increased sediment delivery to streams. In the tropics, water plays a significant role that affects and closely relates to soil erosion and landslides. Excessive farming on steep slopes and frequent rainfall in the tropics contribute to increased soil erosion. Additionally, elements that include slope geometry, slope angle, and soil depth affect soil erosion. According to Ziadat and Taimeh (2013), to prevent soil and water loss, it is vital to use several conservation measures. Planners can advise practical strategies to decrease the amount of soil loss when they are aware of the links between the components leading to erosion processes. The intensity of precipitation, slope steepness, land use and antecedent soil moisture content are the elements that impact soil erosion and surface runoff.

Furthermore, soil erosion assessment is an expensive and time-consuming endeavour. Therefore, a geographic information system (GIS) is a technique used to map soil, identify regions and determine the areas at risk of danger or experiencing alarming rates of soil erosion. Remote Sensing (RS) method enables the measurement of hydrologic parameters on a global scale, whereas GIS incorporates the ability to perform geographic analysis on spatially distributed data. Due to the complexity of soil erosion variables, it is difficult to measure or estimate the extent of erosion precisely. Recent massive advancements in RS and GIS have become crucial in providing precise, timely, and real-time data on different components of the river basin, including land use, soil distribution, relief, drainage characteristics, etc. In addition, it aids in identifying erodible areas and gives data inputs to various soil erosion models. Some model inputs, including the cover factor and, to a lesser extent, the soil erodibility factor and the supporting conservation practice element, can be successfully extracted from remote sensing data.

Besides, it also aids in determining the amount of soil loss. This information is especially beneficial for decision-makers or policymakers who want to protect the environment while also enhancing the safety of people to prevent the danger of soil erosion. It is also extremely useful for them to take action in soil conservation measures to minimize soil loss where necessary. It creates a soil erosion risk map by using RS to obtain spatially distributed characteristics, such as land use and topography. They are then transformed into raster layers and entered into a GIS environment. Remote sensing offers a practical solution to this issue. GIS are superior for managing and utilizing the vast amounts of data collected with the help of remote sensing techniques. By using this method, research on soil erosion in Malaysia has been carried out. In order to create soil loss evaluations, the GIS technique is frequently used (Ahmed, et al., 2018).

1.2 Importance of the Study

Numerous models for predicting soil erosion have been developed in the past few decades. In the beginning, the Universal Soil Loss Equation (USLE) is introduced, and it is a well-known model for estimating agricultural land surface erosion. Afterwards, Renard, et al. (1997) revised and renamed the USLE model as the Revised USLE (RUSLE). RUSLE model calculates soil loss based on five factors: land cover management, soil erodibility, topography, rainfall erosivity, and support practice. Typically, these variables are generated from on-site observations and a remotely sensed digital elevation model (DEM). For various land-use types, including rangelands, forests, dispersed areas, and steep slopes, the RUSLE model can predict soil loss. As a result, planning for conservation at the level of specific properties has regularly been employed by using this model. With a small dataset, RUSLE is unable to represent soil loss in a sizable watershed spatially. To assess soil loss and associated spatial variability at the river basin scale, the RUSLE can be used with RS and GIS. The effective use of RUSLE in conjunction with GIS and RS for measuring soil erosion in river basin has been well-documented.

Therefore, the RUSLE model is the most effective method for predicting soil erosion as an empirical model because it requires less data and time to simulate while providing better visualisation of the spatial distribution of soil erosion integrated with GIS and RS. This model requires several fundamental variables relating to slope, land use, soil type, and rainfall to predict soil erosion (Islam, et al., 2020). The RUSLE model assists in identifying regions at risk of soil erosion as well as the root causes of erosion, including topography, soil type, rainfall intensity, and land use. According to Ganasri and Ramesh (2016), the RUSLE model can determine the geographical distribution of soil loss across a wide area by forecasting erosion risk on a cell-by-cell scale. Researchers can identify regions with the highest rates of soil erosion and prioritise soil conservation actions to stop future erosion and preserve soil fertility through assessing soil erosion rates using the RUSLE model. The RUSLE model can be used to evaluate the potential impact of land use changes on soil erosion rates. By evaluating soil erosion rates before and after land use changes, policymakers and land managers can make informed decisions about land use planning to minimize soil erosion and maintain soil productivity.

1.3 Problem Statement

Concerns about soil erosion and the deterioration of water quality in numerous Malaysian river basin systems have grown in recent years. Serious soil erosion may endanger the ecosystem, agricultural practices, and water supplies, diminishing the capacity of reservoirs and environmental sustainability. This is because it results in the degradation of soil, nutrient loss from the earth, and a variety of secondary environmental issues like floods, river silting, and water pollution. One of the most significant environmental issues the world is currently dealing with is soil erosion. In Malaysia, soil erosion has recently emerged as a significant environmental issue, particularly in regions where land is being used heavily for development, including urbanisation and agricultural operations. The sustainability of agricultural activities has been endangered by soil erosion in agricultural land (Ahmad, et al., 2020). Environmentally sensitive areas have been invaded by development, which has hastened soil erosion, water pollution, sedimentation, and resultant flooding in downstream areas. The communities close to the afflicted areas have also been significantly impacted. Land clearing for the building has been found to provide approximately 90 % of the sediment load to waterways in metropolitan areas. To prevent soil erosion in Malaysia, proper conservation measures should be taken (Academy of Sciences Malaysia, 2017).

Cropland soil is being swept and washed away from the world 10–40 times more quickly than it is being restored. The most significant environmental issue the world is dealing with is soil erosion, which is only surpassed by population expansion. According to German Advisory Council on Global Change (1994), soil erosion caused by water accounts for 1.1 billion hectares (56 %) of land degradation in the world. Global soil erosion by water averaged 20 to 30 gigatonnes per year over the past ten years (FAO, 2015). 30 to 40 times more soil is being lost in India and China than is replenished naturally, whereas ten times more soil is being lost in the United States than is naturally replenished. 30 % of the world's arable land has become useless due to erosion over the previous 40 years (Pradhan, et al., 2011). Future land usage and soil sustainability are expected to be under pressure from the rapidly increasing global population. It is discernible that the most significant elements in the occurrence and intensity of soil erosion are human activity and change in land use, which are the main sources of soil erosion. The degradation of soil, including soil erosion, soil acidity, and loss of organic matter, is significantly impacted by human-induced changes to land use or soil cover (Omar, et al., 2018). The inherent complexity of landscape systems, regional variability, and a lack of data are major obstacles to distributing erosion modelling. Additional study on soil erosion prediction is required because the quantitative assessment of regionally distributed soil erosion has not been adequately addressed. Assessing soil erosion at the plot or catchment levels has received a lot of attention.

The RUSLE model was initially created to evaluate the risk of soil erosion for small, regional river basins. However, the implementation of the RUSLE model has inherent disadvantages with regard to application costs, site representativeness, and the accuracy of expected results due to the spatially extensive occurrence and acceleration of the soil erosion process and water quality issues. As a result, using the conventional RUSLE model to map the soil erosion distribution is frequently challenging. The development of GIS technology sparked a meteoric rise in the use of GIS-based models at the regional level. The effectiveness of evaluating the spatial distribution and degree of erosion risk with acceptable prices and greater accuracy has increased with the use of GIS technology in conjunction with erosion models like the RUSLE model (Jahun, et al., 2015). This study has attempted to develop a new model for soil erosion prediction by utilizing satellite remote sensing with the help of the RUSLE model.

1.4 Aim and Objectives

The research aims to utilise the satellite remote sensing technique in soil erosion assessment in Klang River Basin.

In order to achieve the aim above, several objectives are defined. The objectives of the research are listed below:

1. To investigate the effect of different meteorological and hydrological parameters on soil moisture in Klang River Basin.
2. To predict the annual soil erosion rate by integrating the RUSLE model with remote sensing data in the GIS environment.
3. To compare the relationship between soil moisture and annual rates of soil erosion in Klang River Basin.

1.5 Scope and Limitation of the Study

The study area is limited to Klang River Basin. Convectional downpours have been observed to exceed 200 mm/hr in Malaysia. Such a heavy downpour is very detrimental to exposed soils. Urbanization, industrialization, and population growth have resulted in major environmental degradation and flooding issues, which span nine local government bodies around the Klang River basin. More than half of the Klang River basin is already urbanised, and a significant portion of this ongoing urban expansion has occurred on terrain that is prone to floods. The majority of rivers have high sediment loads, particularly those that flow through Klang Valley. Besides, massive sediment flows into streams, and soil erosion has been brought on by construction. An increase in the impervious surface area of Klang River Basin brings on flooding. Rapid changes in land use have recently exacerbated soil erosion in the basin and significantly altered the hydrological processes. Increased soil erosion can severely affect the flood susceptibility and water quality of the basin. Therefore, soil erosion-sensitive zones in the Klang River basin must be marked off immediately to take the appropriate action to reduce river sedimentation and soil erosion around the basin. In this research, the RUSLE model will be applied to conduct the soil erosion assessment in Klang River Basin. The RUSLE model is used in conjunction with a GIS to evaluate the spatial characteristics and patterns of soil erosion vulnerability in the Klang River Basin, Malaysia. In order to investigate the study area of Klang River Basin, the parameters in the RUSLE model are studied and investigated to identify the mapping of soil erosion for the basin.

1.6 Contribution of the Study

Landslides are primarily caused by soil erosion; therefore, prevention is vital for preventing landslides. Establishing a soil erosion risk map for the Klang River Basin is crucial for implementing effective environmental management and land use planning strategies. It is essential to evaluate the predicted rates of soil erosion caused by the change in the climate.

A critical step in determining potential environmental and agricultural concerns related to rising erosion rates is modelling future erosion rates. There is a chance that climate change will increase soil erosion rates and its negative repercussions.

In this research, RUSLE model was integrated with a GIS to generate a soil erosion risk map for the Klang River Basin. A map overlay of RUSLE parameters was utilised in ArcGIS to map the danger of soil erosion, identify regions at risk, and determine the rate of soil loss in the research area.

1.7 Outline of the Report

The report is distributed into five chapters. The scope and content of each chapter are briefly explained in the following paragraphs.

Chapter 1 begins with an introduction to the topic. In this chapter, there is an explanation of the background study of soil erosion, remote sensing, GIS and the RUSLE model. This chapter also includes the problem statement, objectives of research, scope and limitation, and significance of the study.

Chapter 2 includes the literature review, which reviews relevant literature and previous research on the topic regarding to the soil erosion to have a better understanding and explanation of the relevance of the study.

Chapter 3 explains the methodology and work plan of how the study is done. This chapter includes an introduction illustrated using a flowchart, study area, study period, data acquisition and processing, and soil loss prediction using the RUSLE model to complete the study.

Chapter 4 presents the results and findings of the project. The results are analysed and discussed thoroughly. The data are organized and demonstrated clearly in graphs, figures and tables. The findings are discussed in depth to establish the validity of the results.

Chapter 5 summarizes the main findings or results of the research by restating the achievement of the research objectives. It discusses the significance of the findings and provides recommendations for future study or practical applications.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter includes a synthesis of the available literature regarding the research topic. Firstly, the concept and factors that contribute to soil erosion were discussed. Secondly, the impacts of soil erosion and several conservative measures for reducing soil erosion were analysed. Thirdly, soil erosion prediction models and parameters of RUSLE were studied thoroughly. Furthermore, the introduction and application of RS and GIS techniques were included in this chapter. Lastly, a conclusion summarising the central theories and ideas for better understanding was provided.

2.2 Soil Erosion Concept

When the force of water separates and removes soil particles, a process known as soil erosion takes place. Soil erosion is defined as a complex process that is dependent on soil characteristics, the slope of the land, the presence of vegetation, the intensity of rainfall and the amount of precipitation (Montgomery, 2007). It is well known that changes in land use can potentially speed up soil erosion significantly. It causes the soil to deteriorate gradually. It is also known that agriculture will eventually be less viable if soil erosion exceeds soil production. Soil erosion typically pertains to the degradation of soil caused by the actions of wind and water (Morgan, 1985). Soil erosion predominantly happens when soil is exposed to intense winds, heavy rainfall, and water movement. Certain human activities, specifically agriculture and land clearing, can increase the susceptibility of soil to erosion. Besides, soil erosion is significantly influenced by the climate. Rainfall and water level changes can cause soil to move. Topsoil may be more susceptible to erosion due to significant temperature swings.

Soil erosion is a significant issue for water quality and land quality. In general, soil erosion is a conflict between two forces: the gravity that holds soil in place and the movement of water or wind. The effectiveness in reducing erosive forces and enhancing soil stability determines the capacity of soil to remain in place (Mulvihill, 2021). Sediment control should be an essential element of any soil management approach that intends to enhance soil and water quality. The transition to agriculture from natural vegetation will lead to soil erosion. Soil erosion leads to a decrease in both the quantity and quality of soil ecosystems. As soil surface runoff increases, the effect of soil erosion on water quality becomes considerable. Soil erosion and sediment generation are strongly connected. The most effective strategy for reducing sediment production is stabilising the sediment source by decreasing erosion. Many soil and water conservation strategies have been implemented all over the globe to mitigate excessive soil erosion (Huang, et al., 2022). It is possible to minimize soil erosion by enhancing the rate of soil infiltration, which will result in less surface runoff.

2.2.1 Types of Soil Erosion

Sediment dissociation, transport, and deposition by wind comprise wind erosion. It is a physical and dynamic process involving the transfer of loose, dry, bare soils by strong wind (Zobeck and Scott Van Pelt, 2011). Wind erosion consists of the movement of soil from one location to another. Wind erosion will cause substantial economic and environmental harm. Beaches, dunes along the coast, and deserts are where wind erosion occurs most frequently. Moreover, wind erosion can also happen in agricultural areas under specific soil conditions. The topography and state of the land are principally responsible for the most damaging wind erosion.

Around 500 million hectares (ha) of land worldwide are affected by the soil-degrading process known as wind erosion, which also produces 500 to 5,000 Tg of fugitive dust annually (Grini, et al., 2005). As demonstrated in Figure 2.1, wind can reposition and erode soils, causing the loss of resources and tiny soil particles, impacting soil health and quality. Wind erosion can be a danger to agricultural productivity and the sustainability of natural resources on Earth. Wind erosion diminishes soil productivity by eliminating the most fertile portion of the soil. This removal of organic matter and clay diminishes the soil's biological productivity and degrades soil structure and biological activity, which are necessary for a healthy soil resource. Wind erosion will pose a threat to humans and other organisms. The soil eroded by wind will be deposited into streams and the atmosphere. It will degrade the quality of water and air.

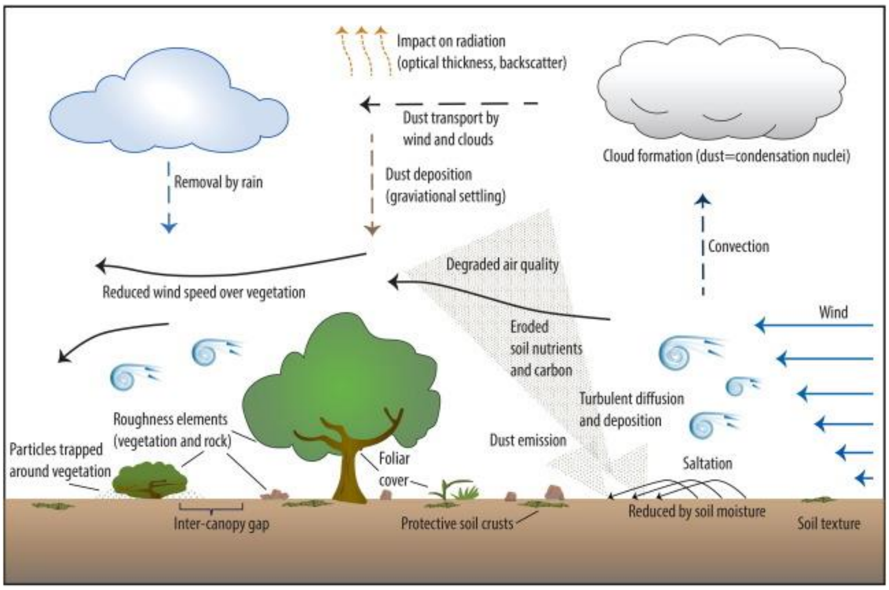

Figure 2.1: Physical Processes that Affect Wind Erosion and Dust Emission (Webb, et al., 2017).

The erosion caused by wind is controlled by several factors, which are wind speed, temperature, rainfall precipitation, surface roughness, soil texture, vegetation cover etc. The three phases of wind erosion are the commencement of movement of soil particles (detachment and deflation), transportation of soil particles (saltation, surface creep, and suspension), and deposition of soil particles. Long-term soil degradation processes may substantially impact the soil's physical properties. The largest particles remain on the soil, whereas the wind will help to transport the finer and more valuable soil particles. Numerous fertile regions around the world have diminished soil yield due to wind erosion. The most prominent effect of wind erosion in this world region is the loss of topsoil. Besides, the most fertile portion of the soil surface is physically removed by wind erosion, resulting in a drop in soil nutrient concentration, which is detrimental to plant growth (Lackóová, et al., 2021).

According to Duniway, et al. (2019), wind erosion can be classified into three categories at local scale, which are surface creep, saltation, and suspension. For surface creep, it involves the creeping and rolling of the surface soil particles. Since particles are too heavy to be carried by the wind, they will not easily leave the ground. Large particles having a diameter of between 0.5 mm and 2 mm are involved in surface creep. These soil particles will travel across the ground during a wind erosion event. These big particles move a few metres barely due to surface creep and wind erosion. For the saltation process, the particles with sand-sized are carried by the wind by bouncing and skipping at high speeds while slamming into each other. Saltation happens in middle-sized soil particles that have a size of 0.05 mm to 0.5 mm in diameter. The saltation is caused by particles, which roll on the surface at first before jumping into the air (Burezq, 2020). Suspension is the last type of wind erosion. The most noticeable soil movement is the suspension. It involves dust, silt particles or clay that are released into the atmosphere and may take several days to deposit. The soil particles are carried over very far distances by the suspension. Small particles with a dimension of smaller than 0.1 mm are dispersed into the atmosphere by saltation, where they are carried higher into the atmosphere by turbulence to generate dust storms. The distance that soil particles in suspension travel might range from a few kilometres to thousands of kilometres (Burezq, 2020). Figure 2.2 illustrates the ways of soil particles are transferred by wind through saltation, suspension, and surface creep.

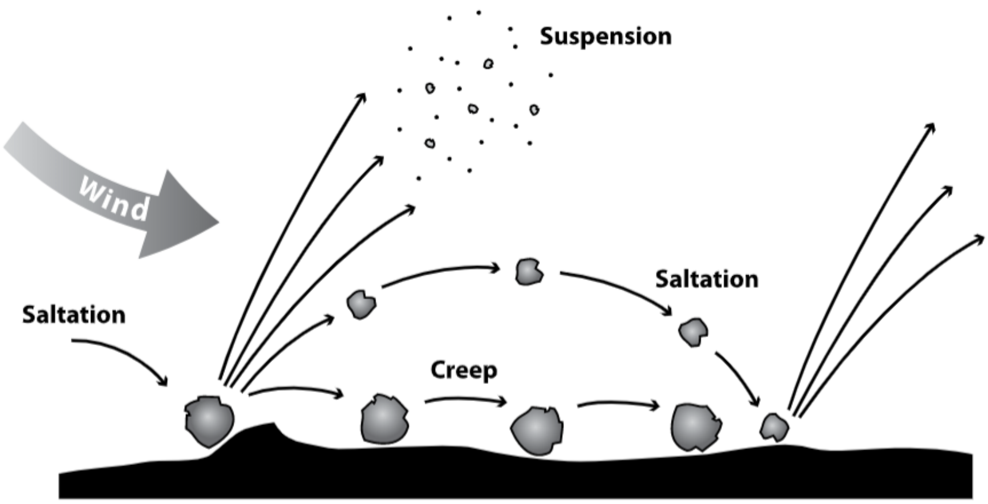

Figure 2.2: The Movement of Soil Particles (Presley and Tatarko, 2009).

The economy, public health, and the environment will all suffer significantly from wind erosion. Wind erosion of soils can have a significant negative impact on ecosystems at the local level by loss of particles as dust, saltation, suspension, and creep (Field, et al., 2010). Wind erosion will affect human health as airborne dust can lead to bronchitis and other health issues. Giant dust storms can arise and linger for several hours when dry, loose soil particles are suspended in the air. These storms can potentially destroy crops, kill livestock, and result in several grave health issues for people. Wind erosion can cause physical injury to plants and biological soil crust. This can reduce plant production, survival and size of plants. Besides, wind erosion will impact agricultural production because it removes organic matter and the fertile top layers of soil. This is because the wind-blown soil can bury crops, sandblast fences, and pastures. Reduced crop yields might arise from airborne soil due to wind sandblasting sensitive foliage and stem or burying plants and seeds. Dust storms will also impact economic activity when they interrupt commerce and transportation. As sediment accumulates over time and alters the soil formation process, wind erosion also alters the topography of the ground. When the subsequent wind event takes it up and moves it somewhere, this sediment building completes the cycle and worsens the situation.

Water erosion refers to the removal of soil by water and the movement of the eroded soil elements away from the place of removal. Rainwater action degrades the soil through rill, stream, and gully erosion processes, having the downstream repercussions of floods and sedimentation (Mclvor, et al., 2014). The greater the amount of water flowing across the ground, the more soil is transported or moved away. The lands with no vegetation are particularly prone to water erosion as there is no vegetation to absorb the water. Rapid soil erosion may result from extreme meteorological conditions, including torrential rains, flash floods, and quick snowmelt. There are several factors that the water will cause erosion: the rainfall intensity, amount of water runoff flows over the ground surface during storms, length and slope of the land surface, soil type, size of soil particles and soil texture. These elements will significantly impact the speed and strength of the water runoff.

Land depletion by water can be natural or accelerated, depending on what contributed to it. Natural water erosion cannot be prevented by humankind and has a minimal impact on soil productivity. Natural water erosion is caused by rainfall runoff or melted snow. Depending on the characteristics of the farmland and the climate where it is located, each soil type has its unique natural erosion rate. On the other hand, illogical farming leads to accelerated erosion. It happens when the fertile layer of the land is destroyed due to the incorrect irrigation method and intensity of water.

Water may be extremely caustic despite being essential for both life and agriculture. Each raindrop splash could impact the structure of soil. Several typical types of water erosion are listed below. Splash erosion is the initial stage of erosion caused by rainfall, which causes the formation of surface crusts and reduces the soil's ability to hold water. Over time, this can lead to the emergence of runoff. Splash erosion is a complicated process that results in soil particle detachment when raindrops hit the soil surface, followed by the movement of the detached particles across short distances (Fernandez-Raga, et al., 2017). Additionally, rill erosion is a type of erosion that results in small yet well-defined channels. Basically, the rill erosion channel is smaller than the gully erosion channel. Rill erosion occurs when there is an accumulation of water in the soil that creates faster-flowing channels. These rill erosion channels will result in the separation and movement of soil particles. The occurrence of rill erosion in hill country is illustrated in Figure 2.3. Eventually, rill erosion might develop into gully erosion. Besides, it is considered an advanced stage of water damage to the ground surface. Gully erosion results from concentrated surface water scouring out the regolith and underlying rock, as illustrated in Figure 2.4. The debris is then dumped downslope or carried into river systems, which causes significant difficulties downstream (Mclvor, 2014). The type of rock significantly impacts the shape and severity of the gully. In gully erosion, each rock type has its unique gully morphology. Gully erosion can make it difficult to cultivate crops and plough fields. Another type of water erosion is bank erosion. Natural rivers, streams, as well as artificial drainage channels are gradually undercut, scourged, and slumped by the vigorous movement of water, which is referred to as bank erosion. when rainwater falls on the soil surface but does not seep into the ground, it evenly distributes soil particles, causing sheet erosion. It can cause the uniform removal of soil in thin layers (Kenny, et al., 2019). The fine soil particles that are the majority of the essential nutrients and organic materials are removed by sheet erosion.

Figure 2.3: Occurrence of Rill Erosion on Hill Country (Mclvor, et al., 2014).

Figure 2.4: Occurrence of Gully Erosion (Mclvor, et al., 2014).

Water erosion is the most harmful type of erosion in the world, seriously degrading the ecosystem and the state of the land (Wei, et al., 2009). The type and depth of the washed-away topsoil determine the impact of soil loss. The capacity of remaining soil to hold nutrients and moisture declines when topsoil is lost. Erosion can lead to flooding and the formation of stagnant water due to decreased soil ability to absorb water. This, in turn, may hinder or prevent planting new crops, particularly if certain areas remain flooded during the planting season. For the impact of soil erosion on flora, plants will inevitably be impacted by the depletion of topsoil caused by the rapid land degradation process. Reduced water holding capacity brought on by soil erosion lowers the number of nutrients and carbon in the water, lowering crop output. The amount of nutrients that are delivered to the plants will be reduced significantly.

Furthermore, flooding is an example of how severe water erosion can damage ecosystems. Flooding brought on by severe land degradation by water can harm ecosystems. Flooding is far more likely to occur in vulnerable locations because the topsoil has decreased its capability to absorb moisture. In severe circumstances, flooding caused by soil erosion can destroy everything in its path. Moreover, the negative impacts of water erosion will eventually lead to wildlife. Animals, fish, and algae are adversely affected by the lack of topsoil because the quality of water is decreased, and contaminants in water are raised. The water supply will also be impacted by water erosion. Reduced water quality issues might result from soil erosion caused by precipitation. As a result, the oxygen content and quality of the water will be reduced.

2.3 Factors that Contribute to Soil Erosion

Soil erosion is one of the environmental issues threatening human existence and progress worldwide (Ai, et al., 2020). Several factors influence or contribute to soil erosion, which is necessary for its occurrence. Soil characteristics, rainfall intensity, vegetation cover, topography, climatic factor, deforestation and human activities determine the soil erosion potential in any area.

2.3.1 Soil Characteristics

Soil characteristics that influence soil erosion by precipitation and runoff include those that impact soil infiltration capacity and resistance to separation and transport by raining or running water. Based on its physical characteristics, soil erodibility will serve as an estimate of a soil's capacity to fend off erosion. Following the organic matter, permeability, and structure, texture has the most significant impact on erodibility. Erosion is often less likely to occur in soils with quicker infiltration rates, higher quantities of organic matter, and improved soil structure. Silt, fine sand, and some clay-textured soils are often more prone to erosion than sandy loam, sand, and loam-textured soils. The agricultural practice contributes to increased soil erodibility by decreasing soil organic matter levels, causing poor soil structure, or resulting in soil compaction. For instance, runoff might increase, and infiltration can decrease due to compacted subsurface soil layers. The susceptibility of soil to erosion is affected by prior instances of erosion. The soil in eroded areas often has a weaker structure and lower organic content, making many subsurface soils more erodible to corrosion than the original soils. Lower nutrient levels commonly found in subsoils can lead to reduced crop yields and poorer crop coverage, resulting in less crop protection for the soil. There are a number of significant characteristics that determine soil erodibility, which are organic matter content, structure of soil, texture of soil, and soil permeability. When managed with conservation methods, all soil textures exhibited significant decreases in runoff and erosion, although coarse-textured and medium-textured soils exhibited significantly bigger reductions than fine-textured soils. The size of soil particles is a crucial component in determining detachment and transport processes (Du, et al, 2022). Soils with a high proportion of fine sand and silt are typically the most susceptible to erosion. The erodibility of these soils decreases as their clay and organic matter levels rise. Clay binds soil particles together, hence preventing erosion. In addition, the most significant indication of soil quality and productivity is soil organic matter, which is made up of a complex and diverse mixture of organic materials.

Plants have increased access to water because soil organic matter enhances soil porosity, which increases infiltration and the capacity of soil to hold water (Jankauskas, et al., 2007). The presence of organic matter holds soil particles together and is crucial in reducing soil erosion. It affects the soil's ability to absorb water. Deterioration of soil structure and permeability is brought on by lower soil organic content. Next, for the soil structure, the composition of soil particles influences the friability of soil or the ease with which rains and runoff can separate soil particles. For soil permeability, high-permeability soils are the least susceptible to erosion from rainfall and surface runoff.

By affecting water-holding capacity, oxygen-holding capacity, soil stability, soil structure, and nutrient storage, soil organic matter is undoubtedly the most significant soil component. These characteristics are essential for preserving and enhancing soil quality. The susceptibility to soil erosion increases as organic matter content decreases. Organic matter is fundamental since it serves as the primary habitat for a wide variety of soil fauna and microflora that are crucial to the health and productivity of soils (Bullock, 2005).

2.3.2 Rainfall Intensity

It has been determined that rainfall intensity is the most significant factor influencing runoff and erosion. Rainfall precipitation is one of the most influential factors in soil erosion. Soil erosion is mainly caused by rainfall, which has a direct impact on the disintegration of soil aggregates, the separation of sand particles, and the movement of eroded materials. As a result, rainfall is considered to be the primary factor responsible for soil erosion. When raindrops strike the ground, the kinetic energy produced will result in rainfall erosivity. Theoretically, the magnitude of kinetic energy increases with the intensity of the rainfall. It will result in soil compaction and aggregate destruction. Besides, rainfall sediment is the dissociation and transport of loose soil particles caused by rain splash and surface runoff scouring, which can transfer particles away from the initial location.

75 % of the total soil loss is caused by rainfall with an intensity greater than 0.8 in h^{-1}, which accounts for just 37 % of the total precipitation (Ziadat and Taimeh, 2013). Moderate rainfall with a lengthy duration often leads to interflow. In contrast, storm rainfall events are typically associated with surface runoff, which can have detrimental effects on soil structure and result in soil loss. Runoff and sediment production are mostly caused by storm and rainfall patterns with high intensity, brief duration, and high frequency. Surface sealing, the antecedent unit, and soil compaction can provide enough runoff volume to carry soil particles, which is required to produce soil loss (Meng, et al., 2021). Runoff usually happens when rainfall is higher than infiltration, preventing extra water from percolating (Zhao, et al, 2019). Heavy rainfall will cause greater surface runoff and suspended sediment production.

2.3.3 Vegetation Cover

Vegetation cover has a crucial impact on regional soil erosion processes (Zhou, et al., 2006). Due to changes in vegetation coverage and root biomass density, different forms of vegetation have diverse effects on soil and water conservation. Rain is absorbed by vegetation, lowering its energy and limiting splash erosion. Additionally, it slows runoff, minimises sheet erosion, and anchors and strengthens the soil with its roots.

Compared to bare soil, vegetated areas experience significantly reduced surface water runoff because of interception, surface roughness, and infiltration. Runoff often does not surpass 10 % to 20 % of the total amount of rainfall in small watersheds with vegetation like grass or trees. Without vegetation, this percentage might rise from 60 % to 70 %. Vegetation affects soil erosion by altering the erosivity of rainfall, preventing raindrop splash on the soil surface, and lowering soil erodibility (Tang, et al., 2021). Water movement across a bare soil surface erodes and moves soil particles that have already detached. Vegetation restricts the movement of water and shields the soil surface from its impact, thereby reducing the capacity to separate soil particles and transport sediment by limiting runoff velocity. With the help of vegetation, the infiltration rate of the ground surface increases. Plant roots generate openings or fissures where roots have perished, reduce soil density, and enhance the structure of soils on the ground surface. The rate at which precipitation and surface runoff is absorbed into the soil increases.

2.3.4 Topography

The shape, size, and slope of a watershed determine the runoff volume and velocity. As a slope's length and gradient grow, the runoff rate and the potential for erosion increase. Erosion threat increases with the length and steepness of the slope of a field. As the length of a slope increases, soil erosion caused by water intensifies due to the higher build-up of runoff. Merging smaller fields into larger ones frequently leads to longer slope lengths with increased erosion potential because higher water velocity promotes greater sediment scouring. Soil development is significantly influenced by topography. The soils on a hill's slope often have shallow depths because of erosional losses. Valley soils are often deeper, darker, and contain more horizons. Midslopes have the highest erosion rates, followed by valleys. Similar erosion rates were seen on ridges, upslopes, and downslopes, but flat areas saw substantially less erosion, demonstrating the same pattern as variation (Sun, et al., 2014). This will result in more significant rainwater accumulation in low-lying areas, greater material deposition from hillside erosion, and material build-up from hill summit leaching.

2.3.5 Climatic Change

The most influential climatic factors on erosion processes in a specific region are precipitation, air humidity, wind, and air temperature. The soil erosion process involves soil displacement through various factors such as water, wind, and mass movement, making climate a crucial contributing factor. (Bullock, 2005). The factors that directly influence soil erosion are precipitation from the atmosphere (erosion caused by water) and wind (erosion caused by wind).

Changes in extreme precipitation are one of the factors that contribute to soil erosion caused by climate change (Nearing, et al., 2004). It is anticipated that extreme precipitation would rise due to the greater moisture-holding capacity of a warmer atmosphere, which will result in a more robust hydrological cycle. Extreme precipitation has an impact on soil erosion both through the influence of raindrops on the soil and through runoff that separates soil particles. The likelihood of climate change increasing infiltration and excess surface runoff increases the possibility of rill and gully erosion, which account for most of the total sediment production.

Due to the continued rise in average temperatures and altered rainfall patterns, soil moisture has drastically decreased. As soil moisture continues to drop, agriculture may require more irrigation, resulting in lower yields and perhaps desertification. Climate change has multiple impacts on soil, including acceleration of erosion due to extreme weather events. Furthermore, the rise in sea levels has the potential to alter coastal soil or introduce pollutants from the ocean, in addition to causing land loss.

In addition, various soil chemical and physical properties are impacted by climate change, impacting infiltration and soil erosion processes. The soil moisture regime, organic carbon content, and canopy cover are the most vulnerable variables to climatic changes. Land-use change is a result of climate change. Land use changes are caused by climate change, and occasionally land use structure changes (Routschek, et al., 2014). Stormwater runoff can carry more sediment when it rains more frequently and with more vigour. In addition to altering the normal sediment distribution along the lake, river, and stream beds, higher river levels and quicker stream velocity can also enhance erosion and increase suspended sediment (turbidity) in the water bodies. These effects on the climate can make it difficult to manage erosion and sedimentation effectively to maintain water quality.

2.3.6 Deforestation and Human Activities

Soil erosion is largely caused by deforestation. According to Gharibreza, et al. (2020), deforestation will lead to unsustainable land-use changes, resulting in various adverse local and global negative effects. Trees and their roots maintain the soil in place and provide protection from the wind and rain. The land becomes vulnerable to being washed or blown away when forests are destroyed because it is unprotected and exposed to extreme weather. The presence of trees and shrubs creates shaded areas that lower the temperature of the topsoil surface, thus reducing evaporation and safeguarding the soil from the impact of heavy rainfall. The process of logging and selective tree cutting results in the exposure of soil to rainwater runoff, which loosens and dislodges soil particles, causing the soil to disintegrate. It creates a more porous bare surface that speeds up runoff.

Flooding will become more frequent and more severe due to deforestation (Lim, et al., 2019). The soil surface develops a crust much more impermeable than soil in its natural state when it is left exposed to the weather and without protection. As a result, less water is absorbed by the soil during raining, and more runoff flows into water bodies. Extreme rainfall events have the potential to result in floods in low-lying locations.

According to Gharibreza, et al. (2020), Soil erosion is significantly attributed to human activities, which include deforestation. Agricultural output, forestry, mining, building construction, and road and building construction have all contributed significantly to global soil erosion. To produce food, especially forage, agriculture must clear plants off the soil's surface. Forage production methods include grazing, mowing, cultivating, ploughing, and other methods of removing vegetation. How vegetation is removed has a significant impact on how much soil erosion occurs. It is much easier for soil to be eroded by wind or water flowing across the soil surface when there is little to no vegetation on the soil surface.

According to Zhao and Hou (2019), overgrazing is one of the human activities that contribute to soil erosion. The animals harm the Earth's surface by devouring the plants and burrowing them into moist soil or compacting dry soil with their hooves. As a result, grass may not grow, and water may move more slowly through the soil. As a result of the removal of nutrients, the soil structure is harmed. Less vegetated soils become exposed, dryer, and more vulnerable to wind and rain erosion. Dryer soils are more susceptible to winds carrying away the topsoil.

Besides, overcropping is another human activity that will cause soil erosion. Overcropping is repeatedly cultivating land without allowing it to rest between harvests. Due to the repeated ploughing or stripping of the soil for crop development, this constant land farming lowers the soil's capacity to produce important humus for soil fertility. The soil loses moisture and fertility. Less humus causes the soil to dry up and become more susceptible to wind and rain erosion. Over-cropping typically happens in regions with a high local or market demand for crops (Zhao and Hou, 2019).

2.4 Impacts of Soil Erosion

Reduced agricultural output and decreased soil quality are the main impacts of soil erosion. According to Bhandari, et al. (2021), soil erosion causes environmental damage, eliminates organic matter and vital nutrients, hinders vegetation growth, and has a detrimental influence on biodiversity. Additionally, blocked waterways could affect water quality. This implies that soil erosion is a significant cause of the environmental issues the globe currently faces. The impact of soil erosion includes the destruction of infrastructure. Soil erosion may impact infrastructure projects, including dams, drainage systems, and embankments. The lifespan and effectiveness of dams, drains, and embankments can be decreased by soil sediment build-up in these structures. These soils can impact infrastructure projects since they are particularly susceptible to most types of soil erosion. If the site is unsuitable for construction and developments via existing drainage systems, it may result in significant soil erosion. Figure 2.5 illustrates the driveways of urban development deteriorate due to erosion. In addition, plant life may be supported by silt, which could weaken the structures by causing fissures. Roads are frequently severely damaged by soil erosion from surface water runoff, especially if stabilising methods are not applied.

Figure 2.5: Deterioration of Urban Development Driveways due to Erosion (Queensland Government 2013).

Furthermore, water contamination and waterway clogging are the impacts of soil erosion. Fertilisers, pesticides, and heavy metals are carried by soil erosion from agricultural lands and wash into extensive waterways and streams. The larger soil particles will be the first to be deposited, whereas the finer clay particles may stay suspended. Besides, gully erosion can transfer the clay particle directly into rivers and streams. This results in water contamination and harm to habitats in freshwater and the ocean. Additionally, accumulated sediments can elevate the water level and choke the waterway, resulting in flooding. Soil erosion has also led to a decline in the water quality of many coastal regions, rivers, and streams, which eventually impacts the wellbeing of the local populations. Settlement and agriculture are both threatened by the development of gully erosion. It results in a loss of arable land and a decline in yields (Jahantigh and Pessarakli, 2011).

Moreover, the topsoil, which is lost because of erosion, constitutes the most productive portion of the soil profile for agricultural use. Crop production and other agricultural practices can have an impact on the entire soil structure as well as the quantity of organic matter it contains, rendering it more vulnerable to the consequences of rainfall and precipitation (Issaka and Ashraf, 2017). Most of the soil properties that sustain agriculture have been lost because of soil erosion, which has led to ecological collapse and widespread famine. Most farmed regions of the world are probably susceptible to soil erosion. The depletion of topsoil will lead to higher production expenses and lower crop yields. Soil erosion will cause the paddocks to become uncultivated when the topsoil is lost.

2.5 Conservative Measures in Reducing Soil Erosion

A group of farming methods and practices known as soil conservation aim to prevent degradation, erosion, and depletion. Techniques for conserving soil are designed with long-term use in mind. Several conservative measures are applied to reduce soil erosion. The use of land for a long time and its continued productivity for future generations is ensured by several forms of soil conservation measures.

First and foremost, on the map produced by the modelling, a systematic plan and policy are established. The implementation of appropriate conservation measures in specific locations can be done using this map by decision-makers. Decision-makers can use this finding as a reference to implement a suitable technique to lower the erosion load, particularly in high erosion rate locations. Strip planting, terracing, or contour farming techniques may be used on specific hotspot erosion locations as part of the necessary treatments to lessen the impact of slope on sediment transport capacity and surface runoff stream velocity (Aga, et al., 2018).

Furthermore, assessing soil erosion is crucial for putting in place the proper practices to reduce soil losses. Rainfall simulators, plot measurements, and modelling techniques based on GIS are currently the most popular techniques used to assess the effects of soil erosion. Additionally, the following landslide and soil erosion management strategies are recommended for the research region. More rigorous deforestation monitoring and vigorous law enforcement are required to stop soil erosion. In hilly terrain, better upkeep of communication structures, roads, and highways is necessary to stop soil erosion. One of the conservative measures to prevent soil erosion is to relocate squatters from hill slopes and restore these areas with forest.

Another conservation measure that can be taken to control and reduce soil erosion and landslides is contour cropping, which entails sowing crops over the slope following contours. Measures for contour cultivation could successfully stop soil erosion, especially in the middle, where severe erosion takes place. For the entire slope, contour cropping decreased soil erosion losses by up to 53.48 %. By switching from downslope farming to contour cultivation, soil losses can be reduced. By shortening the slope, contour cropping lessens erosion. Due to the density of the stems, the crops act as a perpendicular barrier to run-off. Removing the natural drainage channels that naturally arise with conventional cropping down the slope theoretically minimises erosion and run-off. Improved infiltration and lessened soil erosion result from less runoff (Zhang and Li, 2014).

Lastly, the implementation of the model using a computerized system like RUSLE and USLE can control soil erosion. Modelling can be used to anticipate degradation hazards and soil erosion based on data obtained by other methods. Additionally, modelling can be utilised to broaden the application of soil erosion results and build conservation strategies using climate data with a defined return period. The development of models for the risk prediction of soil erosion has been the subject of extensive research. Both water and wind erosion can be modelled using well-tested techniques that have seen extensive use (Pradhan, et al., 2011).

2.6 Models for Measuring and Predicting Soil Erosion

To develop an effective erosion prevention strategy for the sustainable management of resources, it is essential to assess the rate of soil erosion. In areas at high risk of severe damage and requiring more comprehensive measures for soil and water conservation, models depict and simulate the actual hydrological processes. RS has made it possible to forecast the rate of soil erosion. Soil erosion modelling incorporates various complex interrelationships that impact erosion rates by simulating erosion processes occurring in the river basin. To estimate soil loss, the majority of these models require data on soil type, land use, landform, climate, and topography. The models are made to fit a specific set of local characteristics (Thakur, et al., 2018). USLE, RUSLE, and MUSLE are several models that can be applied to estimate soil erosion.

2.6.1 Universal Soil Loss Equation (USLE)

USLE is an empirically based equation that calculates sheet and rill erosion. It was developed from massive field data, including erosion plots and rainfall simulation experiments. In those areas of landscape profiles where erosion but no deposition is taking place, it is used to estimate the average yearly soil loss caused by sheet and rill erosion. It does not estimate sediment yield further downstream or deposition similar to that at the toe of concave slopes. Additionally, it excludes transient gully erosion.

Under precise conditions of land use and management, USLE model was specifically created and tested to forecast the typical yearly soil migration from a certain field plot. The USLE model uses factors such as rainfall patterns, soil types, terrain, crop systems, and management techniques to forecast the long-term average annual erosion rate (Pham, et al., 2018). The model is only applicable to average data over 20 years. USLE is invalid for specific and individual storms.

2.6.2 Modified Universal Soil Loss Equation (MUSLE)

For calculating the amount of sediment load produced by each storm, MUSLE model has been developed, which considers runoff volume instead of rainfall erosivity. The MUSLE is only helpful for estimating soil loss from a single event; neither it nor other models are capable of estimating sediment detachment, entrainment, transit, deposition, or redistribution throughout the watershed. Comparing USLE and RUSLE, MUSLE provides a more accurate forecast of soil erosion since it incorporates runoff as a separate element in erosion modelling (Zhang, et al., 2009). The runoff factor in MUSLE takes the place of the factor of rainfall energy. This enhances the ability to anticipate sediment yield, does along with the requirement for delivery ratios, and allows the MUSLE equation to be applied for specific storm events. Because the output information for this model can be found at the watershed outflow, MUSLE is simpler to apply (Arekhi, et al., 2011).

2.6.3 Revised Universal Soil Loss Equation (RUSLE)

The long-term average annual soil loss (A) transported by runoff from particular field slopes is predicted using the RUSLE model. RUSLE model is applied to estimate the average annual loss of soil. RUSLE model is the revised version of the USLE. RUSLE is just one of several modifications of the USLE, especially for more complicated rill and interrill erosion scenarios in conservation planning. Therefore, both erosion-prone models determine detachment capacity and soil loss.

According to Panditharathne, et al. (2019), RUSLE is applied as a decision support system in soil conservation planning. It describes ecological processes connected to erosion control measures in a given area by using a set of mathematical equations. Additionally, RUSLE can serve as a flexible instrument for evaluating soil erosion when combined with Geographic Information Systems (GIS) on a landscape and watershed scale. RUSLE shows the geographical distribution of soil erosion in addition to providing an estimation of soil loss at the plot scale. To estimate soil loss using the RUSLE model, RS and GIS have developed into precious tools. According to Ghosal and Bhattacharya (2020), for the assessment of average annual soil loss, RUSLE is based on five factors, which are slope length and steepness (LS), support practices (P), soil erodibility (K), vegetation cover-management (C), and rainfall erosivity (R).

2.7 Parameters of the RUSLE Model

RUSLE, is the most extensively used prediction equation in the world. Basically, it is used to forecast the typical rate of soil erosion by combining the various components that influence soil loss into a set of factors. RUSLE consists of five components, the specific numerical values of which vary on the location.

2.7.1 Rainfall Erosivity (R)

The ability of rain to cause soil erosion is rainfall erosivity. It represents the ability of an average yearly precipitation value to produce soil erosion in this study. The complexity of the R factor process makes it susceptible to changes in the length, energy, intensity, quantity, and size of the raindrops, as well as the pattern of precipitation and subsequent runoff rates. It is regarded as having the greatest impact on soil erosion. R factor can be calculated using rainfall intensity. R factor is calculated using the watershed's long-term average annual rainfall data. The rainfall erosivity factor assesses the impact of precipitation in the form of kinetic energy. Besides, R factor is also used to forecast the rate and volume of runoff that is directly related to that precipitation event.

For each storm during a year, the kinetic energy of the storm is multiplied by the most tremendous storm depth for 30 minutes, and the result is added, yields the R factor in RUSLE. R factor signifies the force behind the sheet and rill erosion. Changes in R values are indicative of changes in the erosive capacity of the climate. A seasonal distribution is used in the R factor calculation to weigh the C and K factors (Jain and Singh, 2003). R factor is the major factor that causes soil erosion. R factor is set to be equivalent to the average of the total of the erosivity values for every annual rainfall (Vantas, et al., 2019).

2.7.2 Soil Erodibility (K)

An inherent erodibility of particular soil is quantified by K factor. K factor is a measure of how easily soil particles can get detached and be carried away by runoff and precipitation. The K factor indicates the soil's inherent erodibility and evaluates its susceptibility to separation and transport by falling raindrops and overland runoff (Islam, et al., 2020). The erosion rate per unit erosion index from a typical plot is the soil erodibility factor for a certain soil. When combined with the other erosion-affecting factors, the factor reflects the reality that different soils erode at various rates.

The range of 0.02 to 0.69 is used to compute the K factor. Due to their resistance to detachment, heavy clay soils have low soil erodibility values between 0.05 and 0.15, while coarse-textured sandy soils similarly have low K values between 0.05 and 0.2. Due to the moderate susceptibility to detachment and moderate runoff, silt loam soils, which have a medium structure, have intermediate K values that range from 0.25 to 0.4. The soils that contain a significant amount of silt are most prone to erosion. They tend to crust, easily dislodged, and produce a significant amount of runoff. K values for these soils are typically more than 0.4. The amount of organic carbon present in the soil influences soil erosion. A decrease in K factor resulting from higher organic carbon content leads to reduced susceptibility to soil erosion and increased rates of water infiltration through the layers of soil (Rammahi and Khassaf, 2018). A high rate of infiltration will lower surface runoff and soil erosion.

The K-factor is determined by the soil's texture and structure, hydraulic conductivity, and organic matter content. This factor is quantified using a nomograph based on the variables involved. The soil-erodibility nomograph employing quantifiable parameters is the most popular and commonly quoted relationship for estimating the K factor. The soil erodibility nomograph consists of five soil profile parameters, which are the percentage of modified sand (0.1 mm to 2.0 mm), percentage of modified silt (0.002 mm to 0.1 mm), percentage of organic matter (OM), soil permeability class (p), and soil structure code (s). The soil erodibility factor (K) is measured by using a nomograph, as shown in Figure 2.6. Adjustments are performed to the existing nomograph. It is required to obtain the best correlation between the predicted K value and the relative K value for the Malaysian soil series. After obtaining K values, ArcGIS developed a soil erodibility map of the watershed area by adding the data to the soil map shape file.

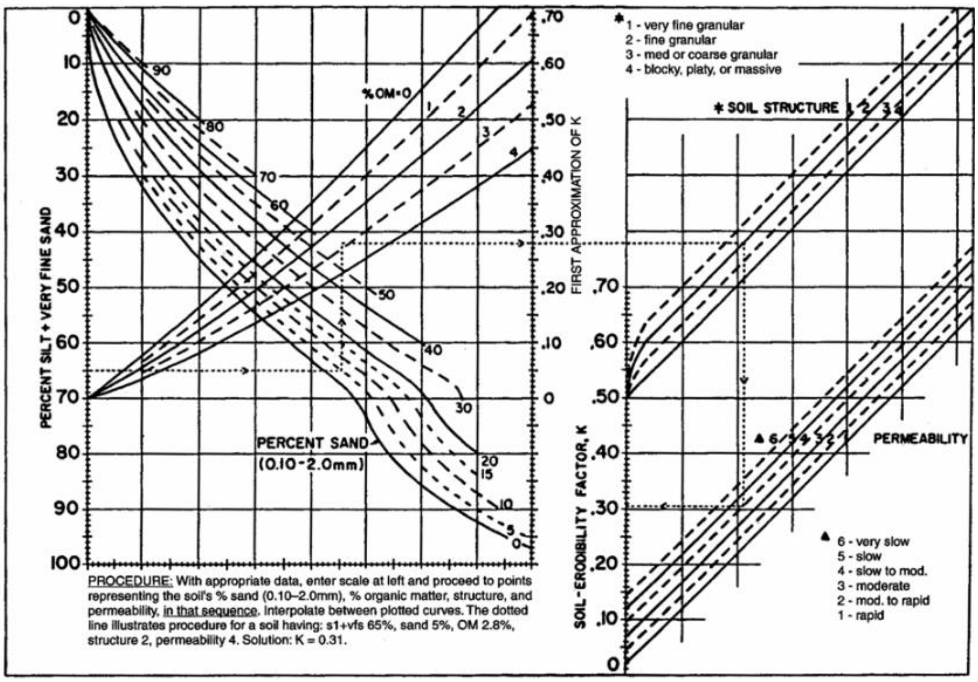

Figure 2.6: Nomograph for Computing the Soil Erodibility Factor, K (Wischmeier, et al., 1971).

2.7.3 Slope Length-Steepness (LS)

LS consists of a total of two factors, which are the length of slope and steepness of the slope. LS factor compares soil loss under specific circumstances and soil loss at a site with a conventional slope steepness of 9 % and a 22 m slope length. The probability of erosion increases as a slope becomes longer and steeper. The LS parameter, which is the result of the product of length and steepness of the slope, is used to evaluate how the topography affects erosion. As the slope length (L) increases, the rising runoff build-up towards the downslope increases soil erosion. Similar to how runoff velocity and erosivity increase as slope steepness increases (Allafta and Opp, 2022).

Slope length is the measure of the distance between two points. The slope length has an impact on erosion, and it is known as L factor. As a result, the soil loss increases in conjunction with an increase in slope length. S factor refers to the impact of the steepness of the slope on erosion. Compared to slope length, slope steepness has a more significant effect on soil erosion. The worst soil erosion occurs at slope steepness between 10 % and 25 % (Islam, et al., 2020).

When soil particles are displaced by runoff or raindrop impact, slope length and slope steepness have a significant impact on their travel. The LS factor can significantly affect the expected erosion because it can be characterised as being substantially more than unity. Averaging over huge areas is not suggested due to this reason.

2.7.4 Cover-Management (C)

Together with the slope length and steepness component, the vegetation cover significantly impacts soil erosion. C factor quantifies the impact of cropping and management strategies on erosion rates. Besides, it is the standard by which comparisons of the potential impacts of various management approaches on conservation plans are made most commonly. C factor indicates the effect of the conservation plan on the average annual soil loss. The vegetation cover diffuses the raindrop energy before it reaches the soil surface, preventing raindrop impacts on the soil surface. The type of vegetation, growth stage of vegetation, and plant cover percentage all affect the C value (Jazouli, et al., 2017).

C factor ranges from 0 to 1. It includes the crop or vegetation cover's prevention effects. Under all other circumstances, it is lower than 1 and it becomes 0 if the land use entirely prevents erosion. For the C factor that is equal to one, this means that there is no land use that serves as a preventative measure to the erosion.

In comparison to other field-available characteristics, vegetation cover contributes significantly more to reducing soil erosion, and it has a negative connection with soil erosion. The process can enhance the ability of soils to absorb water, reduce the velocity of water flowing over the soil surface, lessen the kinetic energy of falling rail droplets, and strengthen the interlocking mechanism between soil particles.

Experimental soil erosion plots with real-world rainfall must be used to calculate the C factor, but these investigations are costly and time-consuming. Remotely sensed data is a widely utilised method for estimating the C factor. The estimated C factor values have not been compared to the estimated C factor values from the data of measurement, which could lead to uncertainty in the estimation of soil erosion (Almagro, et al., 2019).

2.7.5 Support Practice (P)

P factor in the RUSLE model is a parameter that represents the effect of various conservation practices or management practices on reducing soil erosion (Panagos, et al., 2015). P factor describes how erosion control measures work. Some soil-management techniques include tillage, close-growing vegetation strips, deep ripping, terraces, diversions, etc. These practices will result in the reduction of runoff, collection of moisture and storage of moisture.

P factor includes the impact of control measures on runoff concentration, drainage patterns, runoff concentration, hydraulic forces and runoff velocity that the runoff applies to the soil surface to limit the potential for erosion caused by runoff (Panagos, et al., 2015). By implementing these assisting conservation methods, the value of P factor decreases as the volume and velocity of surface runoff decrease and sediment deposition is facilitated on the slope's surface. The approach is more effective in reducing soil erosion with a lower value of the P factor.

2.8 Integrated Remote Sensing (RS) and Geographic Information System (GIS)

After selecting the appropriate model for every RUSLE parameter from the prior review in accordance with the needs of the study area, every parameter is then examined by GIS and RS because these techniques solve the issue more quickly and with lower estimation costs than other field-based general computational techniques. Recently, numerous researchers have employed RS and GIS technologies for soil loss assessment modelling. These studies have revealed that RS's ability to provide current ground data and GIS's capacity to manage vast quantities of spatial data expedite the assessment of soil erosion potential in a region. (Kumar, et al., 2014).

By combining RS and GIS, soil erosion mapping can identify regions susceptible to severe soil erosion and provide insights into the expected level of soil loss at various locations. This information is beneficial when making decisions about whether to avoid land acquisition in locations with a high risk of erosion or if development is to proceed, to suggest soil conservation measures to prevent the rate of soil erosion (Baban and Yusof, 2009).

For instance, in Malaysia, the soil erosion research for the Bakun Dam project, the soil erosion risk assessment and soil risk mapping for Langkawi Island and Genting Highlands were all carried out using GIS. The typical application of GIS is to create assessments based on deterministic, rigorous decision-making processes. Soil erosion, land loss, and land cover changes can all be monitored and determined using GIS techniques in Klang River Basin. The most efficient ways to show the geographic distribution of soil erosion are through GIS and RS, especially when combined with RUSLE.

2.9 Summary

Soil erosion is the gradual transport and movement of soil by water, wind, and mass movement. Long-term soil deterioration is due to soil erosion. The process of soil erosion is intricate and reliant on various factors, such as soil properties, vegetation, slope of the ground, and precipitation. Soil erosion is one of the primary causes, indicators, and determining factors utilised to evaluate and comprehend land deterioration. Erosion of the soil is caused by unsustainable land usage and other disturbances. The loss of soil may severely affect the amount and quality of soil ecosystem services, with significant economic, social, and political consequences. Due to human activities, soil erosion that was natural before, like any other erosion is considerably accelerating. In some areas, the rate of soil erosion can be up to 10 times its regular speed. Before implementing effective methods and measures against soil erosion, it is necessary to forecast the erosion rate. Using a GIS integrated with the RUSLE model, possible locations for soil erosion were identified and assessed, and the value of widespread soil loss was estimated. The soil erosion risk map was generated using the RUSLE model and overlays of specific RUSLE parameter maps. Physically, empirical soil erosion models are relatively straightforward and easier to interpret. The soil erosion model takes minimum resources and can be formulated with readily accessible inputs for places with a high risk of soil erosion. The use of RUSLE model that is coupled with GIS is crucial to calculate potential zones for soil erosion in the Klang River Basin. The distribution of various erosion-prone locations in the Klang River Basin was determined using the RUSLE model. The results would aid in implementing appropriate erosion control strategies in badly affected areas. The study's findings can be used to help create management scenarios and give policymakers choices for handling soil erosion threats in the river basin in order of priority for remediation.

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

A systematic approach to discovering the solution to a particular issue or objective is known as the research methodology. This chapter discusses the entire methodology to achieve the research objectives. The comprehensive process flowchart for soil erosion assessment by using RUSLE was described. The study area of the Klang River Basin was discussed. The climatic data for the precipitation, specific humidity, wind speed, air temperature, and soil moisture were collected from Giovanni. In addition, the data acquisition and processing of RUSLE parameters were explained. Afterwards, the prediction of soil loss and the generation of potential erosion maps using various data inputs were outlined.

The RUSLE model is based on the primary factors that significantly contribute to soil erosion processes and combines the data of about five parameters. It is used to estimate annual soil erosion by performing a geographic simulation of erosion processes. To execute the RUSLE model, the geographical and temporal data for each factor in Klang River Basin were collected and modelled, including meteorological data from weather stations, land use data at regional size from satellites, topography data, soil type data, etc. The results were used to discuss the annual rates of soil erosion in the Klang River Basin. The overall workflow of the study was illustrated in Figure 3.1.

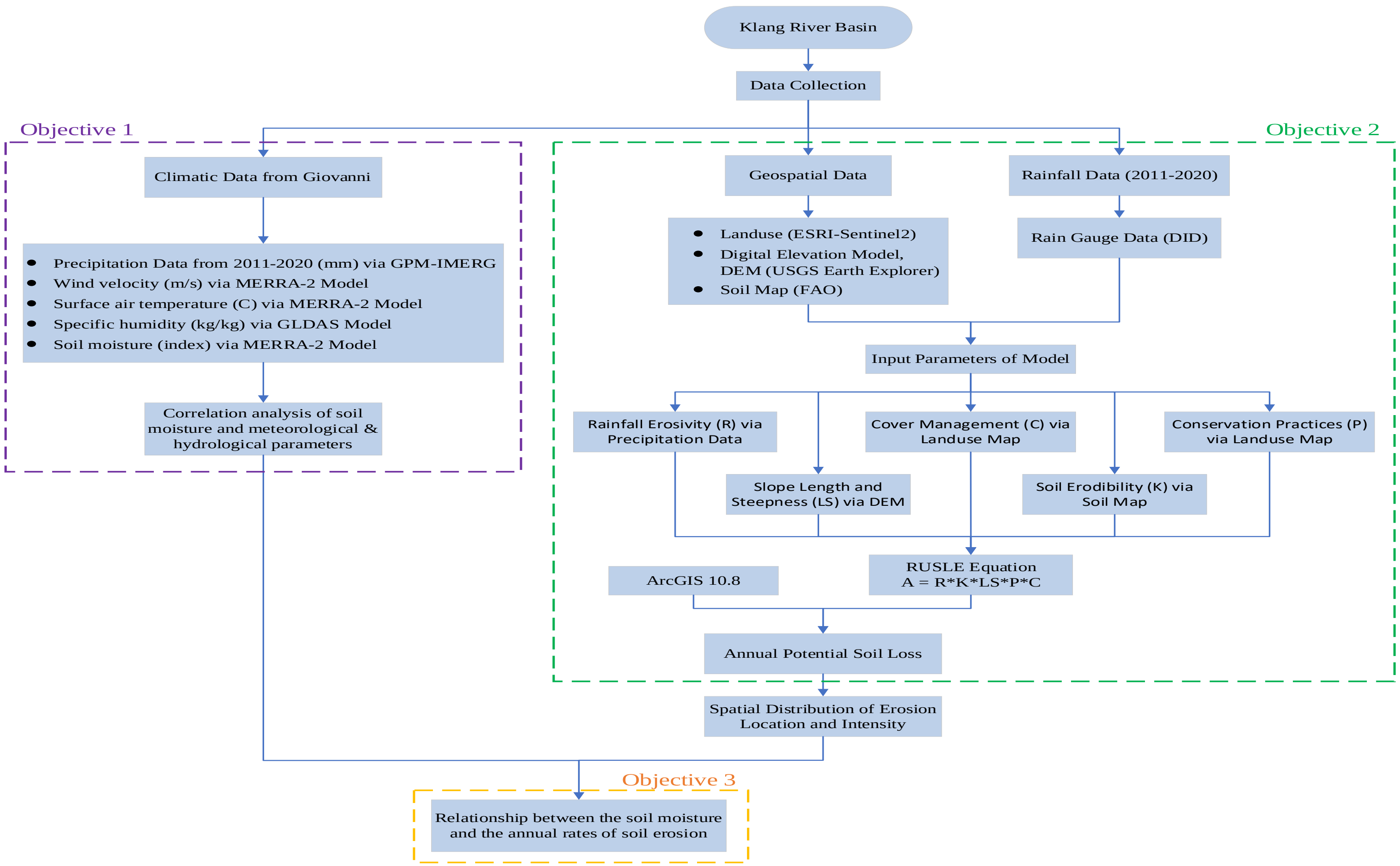

Figure 3.1: General Flowchart of Methodology.

3.2 Study Area

3.2.1 Klang River Basin

The Klang River basin is situated in the most urbanized region in Malaysia. The Klang River Basin is a watershed in Malaysia that includes Kuala Lumpur and Selangor and drains into the Straits of Malacca. It has a length of roughly 120 km. The whole catchment area of the Klang River basin is about 1288 km^2. On the west coast of Peninsular Malaysia, the Klang River Basin occupies up to the central third of Selangor State. Geographically, the Klang River Basin is situated at 3° 00' 0.00" N (3.000° N) and 101° 22' 59.99" E (101.383° E). Figure 3.2 illustrates the location of the Klang River Basin in Peninsular Malaysia. Klang River Basin has an annual population rate of more than 5 %, and it is the most heavily urbanized region in Malaysia, with a population of approximately 7.5 million. An estimated 4.4 million residents making up 16 % of the total population are located near the Klang River basin. It has a total of eleven significant tributaries. The Gombak River and the Batu River are the two principal tributaries of the upper basin. Before joining the Klang River in the City Center, they converge on one another. The Gombak and Hulu Langat districts of Selangor are situated in the upper watershed, an area characterized by mountainous terrain and dense tropical forests. The populated urban areas in Kuala Lumpur make up the middle catchment. Besides, the Selangor districts of Petaling and Klang are part of the lower catchment. Figure 3.3 illustrates the rivers and the catchment area of Klang River basin. The basin has an annual mean rainfall of between 1900 mm and 2600 mm. It has a daily mean humidity of roughly 80 % to 85 %, and the monthly average temperature of the area is between 26 °C and 28 °C (Azari, et al., 2020).

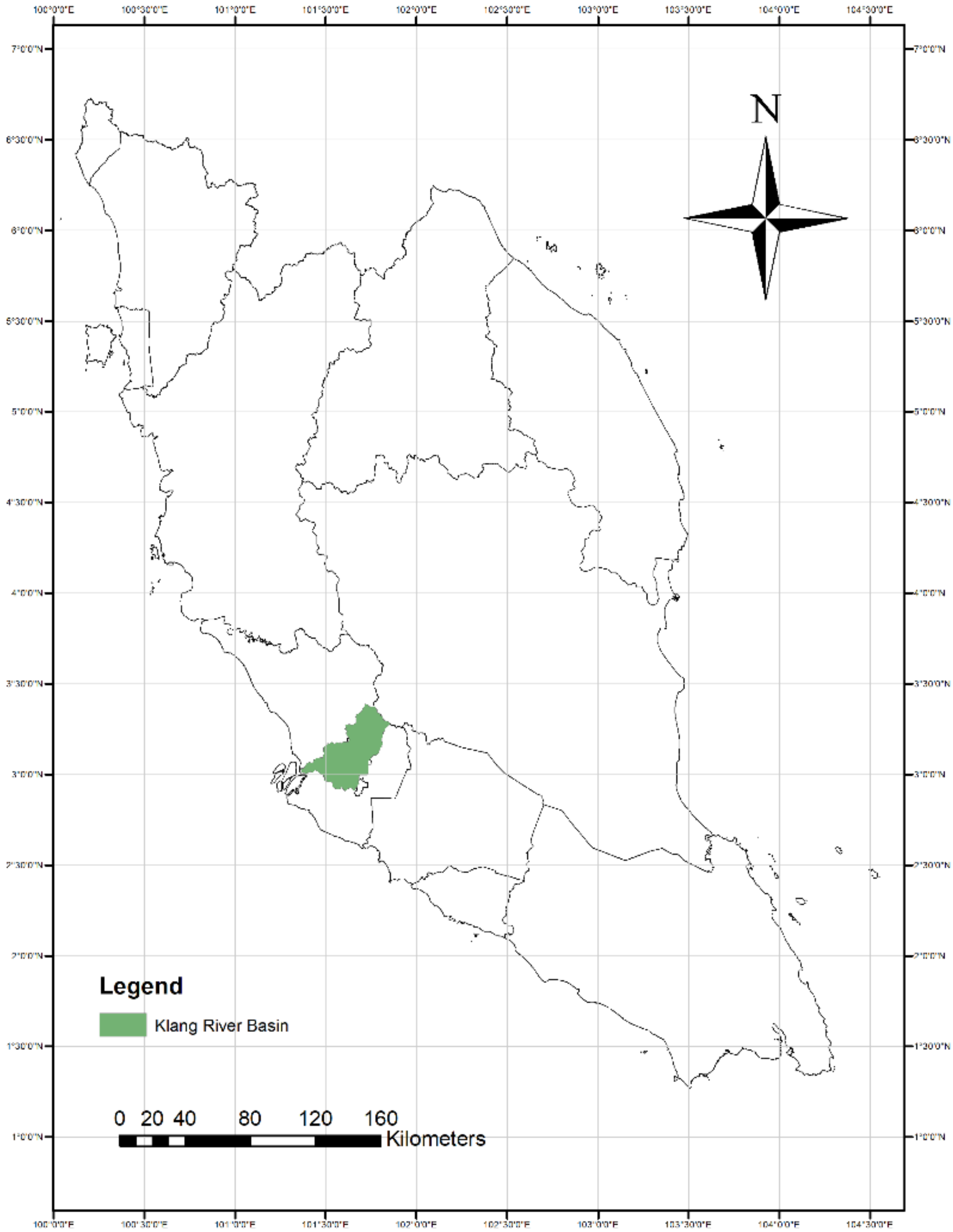

Figure 3.2: Location of Klang River Basin in Peninsular Malaysia.

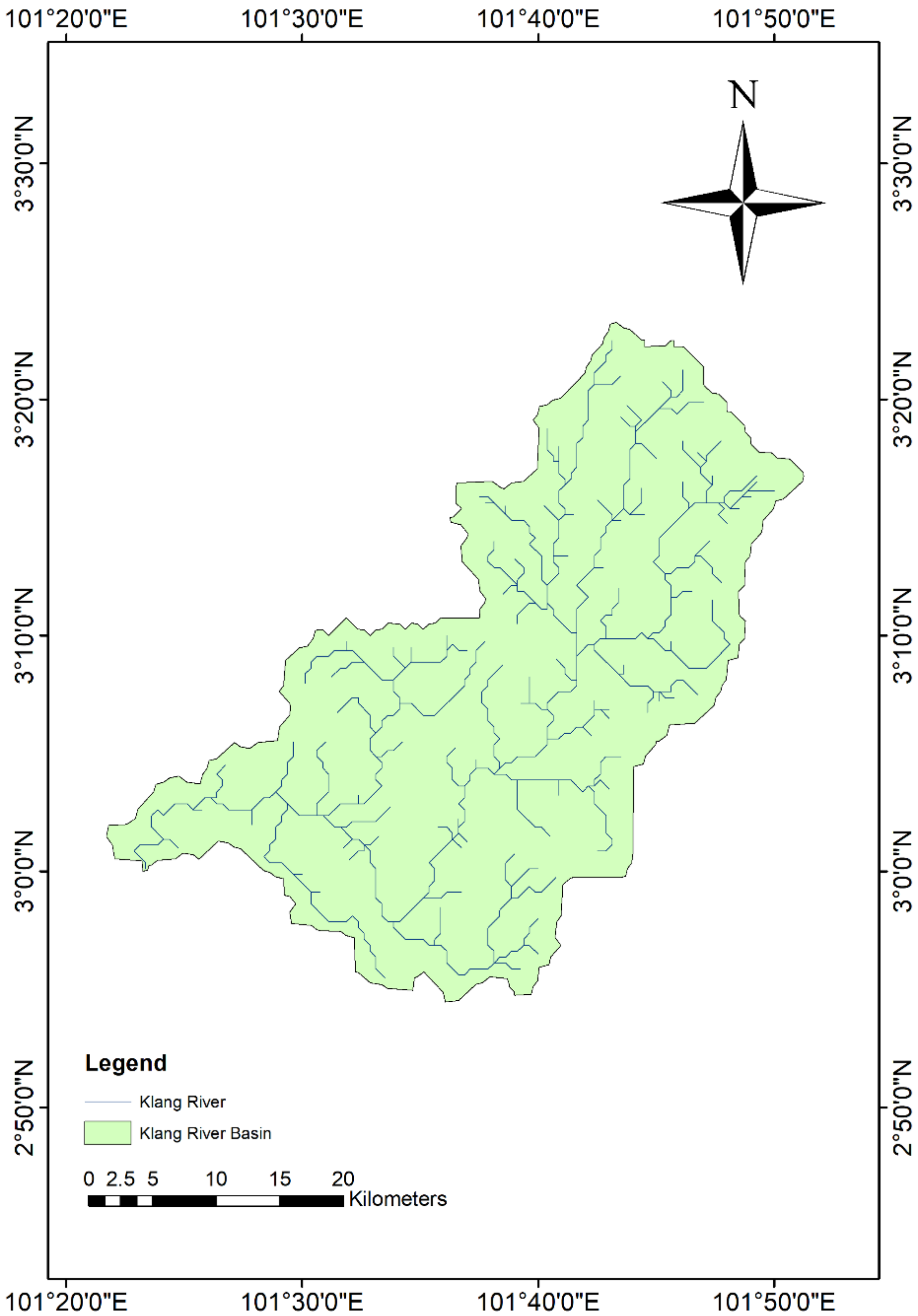

Figure 3.3: Rivers and Catchment Area of Klang River basin.

3.3 Data Acquisition and Processing

RUSLE model predicts slope soil deterioration in the GIS platform. It involves an equation that combines land cover and geophysical parameters to calculate the annual soil loss. The data required for the model are rainfall data, land use or land cover, soil map or soil data, length and steepness of slope, and erosion control practice.

3.3.1 Climatic Data

The climatic data for the specific humidity, wind speed, air temperature, and soil moisture were collected from NASA Giovanni. The period for which the climatic data was used for the data analysis. The time range selected for this study is from 1 January 2011 to 31 December 2020. The meteorological and hydrological data for Klang River Basin were collected on a monthly basis. Missing values and outliers limit the amount of data that can be evaluated. It significantly affects the results, reduces the effectiveness of the data, and ultimately undermines the accuracy of the results (Kwak and Kim, 2017). After gathering the data, the data were cleaned, missing values were resolved, and outliers were eliminated. The meteorological and hydrological data were then compared with the soil moisture in Klang River Basin to investigate the effects of meteorological and hydrological parameters on soil moisture. Correlation analysis was used to explore the relationship between these variables. The degree of relationship between two or more variables was typically measured using the statistical approach known as correlation analysis. The findings of the correlation analysis could give insight on the variables that influence variations in soil moisture, which could have significant repercussions for forestry, agriculture, and other land-use techniques.

3.3.2 Rain Gauge Data

Twenty-two rainfall stations were identified in Klang River Basin. The details of the stations are tabulated in Table 3.1. The rain gauge data from 2011 to 2020 for all the identified stations were collected from the Department of Irrigation and Drainage (DID) Malaysia. The purpose of rain gauge data in this study is to estimate soil erosion using the RUSLE model because it provides information about the intensity and distribution of rainfall. Figure 3.4 illustrates the location of rain gauge stations in the Klang River Basin. The collected rain gauge data were used as the input data to calculate the R factor in the RUSLE equation in ArcGIS 10.8.

Table 3.1: Details of Rainfall Stations in Klang River Basin.

Station No.	Station ID	Station Name	River	Longitude	Latitude
1	3013001	Rumah Pam R. Panjang At Selangor	Sg. Damansara	101.53	3.16
2	3014084	Pejabat Jps. Klang At Selangor	Sg. Klang	101.53	3.13
3	3014092	Sek. Men. Raja Lumu At Selangor	Sg. Klang	101.45	3.05
4	3014094	Kg. Jawa At Selangor	Sg. Klang	101.43	3.06
5	3015085	Tugu Keris At Selangor	Sg. Kandis	101.5	3.02
6	3017106	Sg. Serai Batu 12 At Hulu Langat	Sg. Rasau	101.52	3.06
7	3115081	TTDI Jaya Fasa 2	Sg. Buloh	101.56	3.17
8	3115082	Taman Mayang At Selangor	Sg. Damansara	101.56	3.11
9	3218101	Stn. Jenaletrik Lln. At Ponsoon	Sg. Penchala	101.6	3.11
10	3118069	Pemasokan Ampang At Selangor	-	101.8	3.16
11	3114114	Kg. Berembang At Keramat	-	101.66	3.19
12	3116003	I/Pejabat Jps Malaysia At W.Persekutuan	-	101.74	3.17
13	3116006	Ldg. Edinburgh Site 2 At W.Persekutuan	Sg. Klang	101.68	3.15
14	3117006	Klm. T. Banjir Batu Po At Empat Tin	Sg. Batu	101.63	3.18
15	3117070	Pusat Penyelidekan At Jps Ampang	-	101.68	3.22
16	3216007	Taman Ehsan At Kepong	-	101.75	3.15
17	3217001	Ibu Bekalan Km. 16 At Gombak	-	101.64	3.22
18	3217002	Empangan Genting Klang At W.Persekutuan	Sg. Gombak	101.73	3.27
19	3217003	Ibu Bekalan Km. 11 At Gombak	Sg. Klang	101.75	3.24
20	3217005	Gombak Damsite At W.Persekutuan	Sg. Gombak	101.71	3.24
21	3217008	Jam. Petaling At Jln. Klang Lama	Sg. Gombak	101.72	3.25
22	3317004	Genting Sempah At W.Persekutuan	-	101.67	3.08

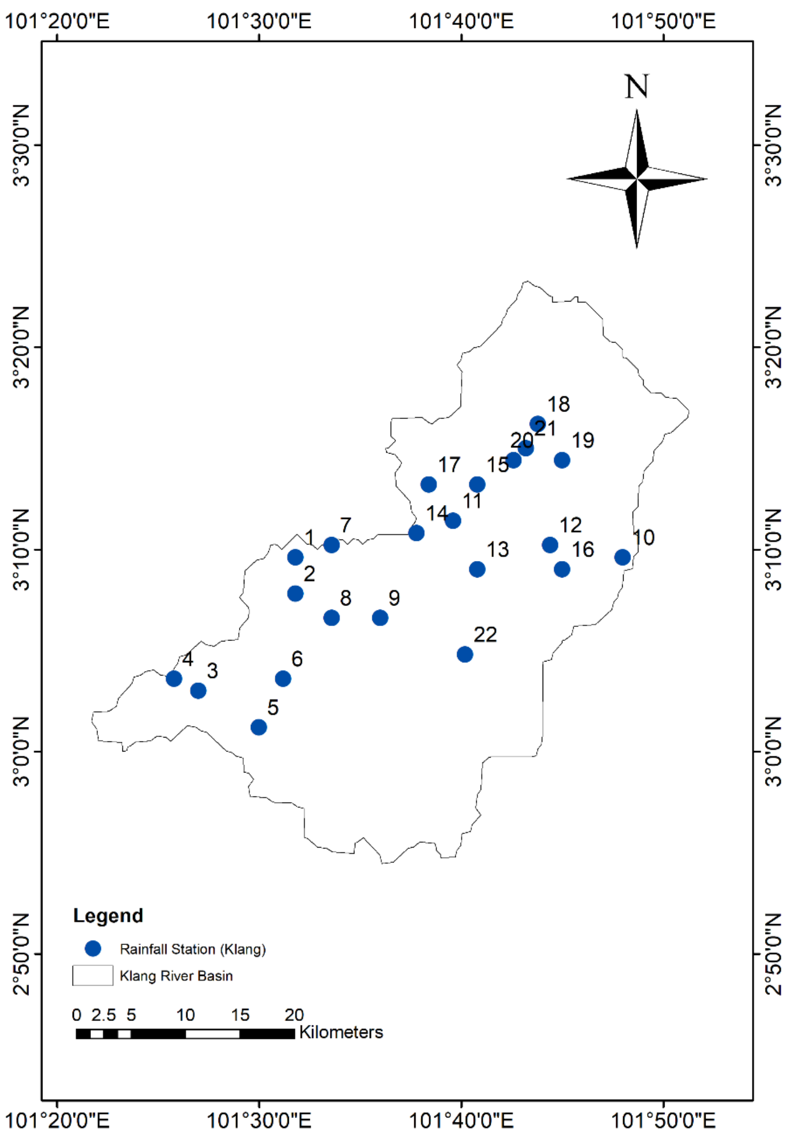

Figure 3.4: Location of Rain Gauge Stations in Klang River Basin.

3.3.3 Land Use

For the impacts of the river basin to be accurately assessed, it is crucial to comprehend the geographical and temporal variations in the historical land use pattern. For the establishment of an integrated river basin management system that is sustainable, land use information is crucial. Land use data is one of the input parameters required by the RUSLE model, and it provides information on the type of land cover in a specific region. The land use map for Klang River Basin was obtained from the ESRI Sentinel-2 Land Cover Explorer. It displays a land use/land cover (LULC) map of the Klang River Basin derived from ESRI Sentinel-2 imagery at 10 m resolution. Different types of land use and land cover in the classification process include water bodies, trees, snow or ice, vegetation, bare ground, built area, crops, clouds and rangeland. Land use data is essential because it determines the C and P factors in the RUSLE model. LULC map was plotted using ArcGIS 10.8 software, and it was illustrated in Figure 3.5. Table 3.2 summarises different types of land use and their coverage percentage in the Klang River Basin.

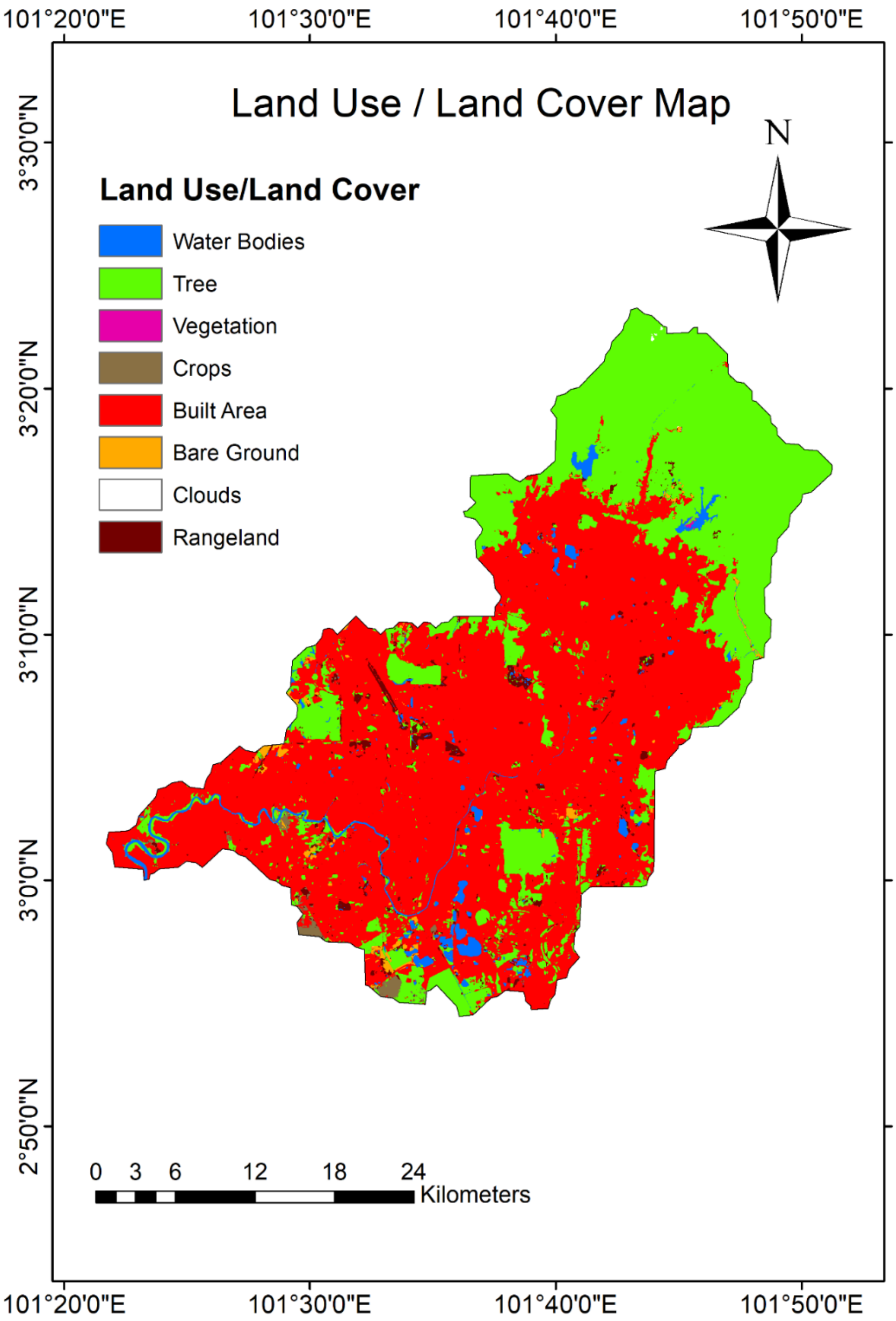

Figure 3.5: Land Use or Land Cover Map (LULC).

Table 3.2: Classification and Coverage Percentage of Land Use.

Land uses	Coverage (%)
Water Bodies	2.49
Forest	30.72
Vegetation	0.02
Crops	0.59
Built Area	63.79
Bare Ground	0.74
Clouds	0.02
Rangeland	1.62

3.3.4 Soil Type Map

The soil map retrieved from Food and Agriculture Organization (FAO) is a global soil map. The map provides information on the distribution of soil types around the world. It was used for the K factor in the RUSLE model to estimate soil erosion rates in Klang River Basin.

In the RUSLE model, the K factor is calculated based on the physical properties of the soil, including its texture, structure, organic matter content, and permeability. The soil type map from FAO provides information on these soil properties for different soil types in Klang River Basin. Soil type map plays a significant role in determining erodibility because different types of soil have varying physical and chemical properties that affect their ability to resist erosion. A soil type map provides information on the spatial distribution of different soil types, such as soil texture, organic matter content, and water-holding capacity in Klang River Basin. Soil texture is determined by the varying proportions of sand, silt, and clay present in the soil. Generally, soils with high levels of sand and low levels of silt and clay are less susceptible to erosion than those with higher proportions. Organic matter strengthens soil structure by holding soil particles together.

3.3.5 Topography

A Digital Elevation Model (DEM) is a representation of the topographic surface of Earth, which excludes construction structures, forests and other surface items. DEMs are frequently employed in GIS and are the most popular framework for digitally generated topographic maps. It permits the estimation of surface area and several topographic parameters, such as slope gradient, slope length, and channel network characteristics. The maximum and minimum elevations in the Klang River Basin are important parameters in analysing the topography of the basin, as they provide information on the highest and lowest points in the landscape, which can affect the flow of water and the distribution of resources (Szypuła, 2019). For the landscape and topography modelling in this study, DEM was applied. SRTM 1 Arc-Second Global is a DEM dataset that provides high-quality elevation data for the entire world. SRTM 1 Arc-Second Global dataset for Klang River Basin was collected from USGS Earth Explorer. Figure 3.6 illustrates the DEM of the Klang River Basin. The study area has the highest elevation of 1,418 m and the lowest elevation of 0 m.

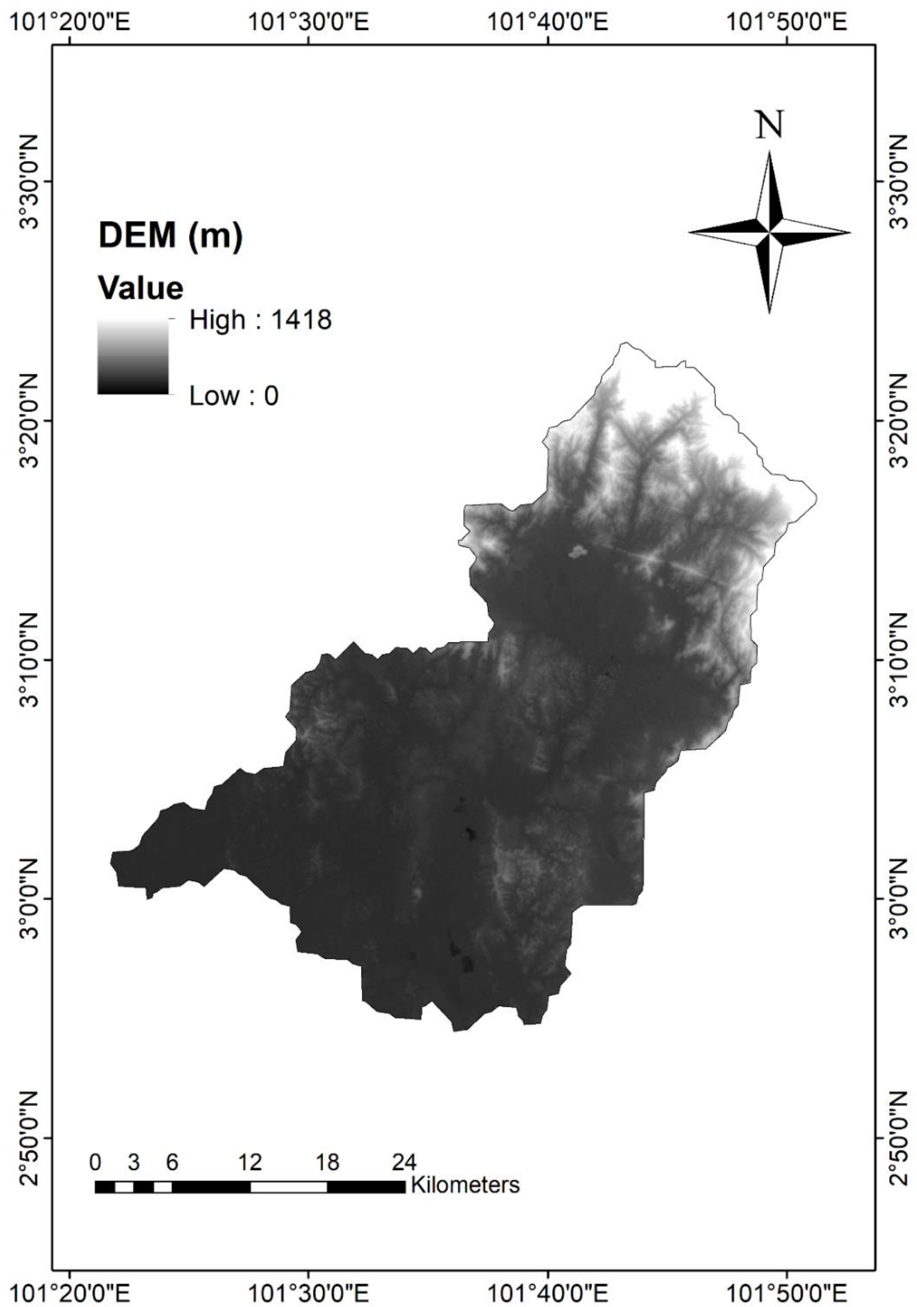

Figure 3.6: DEM of Klang River Basin.

3.4 Soil Loss Prediction (RUSLE Model)

RUSLE is the most widely used prediction equation to estimate the average rate of soil erosion by integrating a set of parameters representing the numerous elements that influence soil loss. Compared to other types of models, RUSLE is easier to adopt and typically produces more accurate results. This research applied the RUSLE model to evaluate the soil erosion scenario in the Klang River Basin. The following paragraphs have substantially outlined the methodology to prepare the RUSLE parameters. RUSLE consists of six components, the specific numerical values of which vary on the location. These five parameters were mapped using the various data inputs collected by ArcGIS. Using the RUSLE relation, these maps are integrated into ArcGIS to generate composite maps of the estimated erosion loss in the research region (Thapa, 2020).

The soil loss equation is shown in Equation 3.1:

$$A = P \times K \times LS \times R \times C \tag{3.1}$$

Where:

A = Average annual potential soil loss ($\mathrm{ton\ ha^{-1}\ year^{-1}}$)

P = Support practice (dimensionless)

K = Soil erodibility factor ($\mathrm{ton\ h\ MJ^{-1} mm^{-1}}$)

LS = Length and steepness of slope factor (dimensionless)

R = Rainfall erosivity factor ($\mathrm{MJ\ mm\ h^{-1}\ ha^{-1}\ year^{-1}}$)

C = Cover-management factor (dimensionless)

3.4.1 Rainfall Erosivity (R)

R factor measures the influence of rainfall and also takes into account the volume and pace of runoff that will likely be brought upon by precipitation events (Tirkey, et al., 2013). Obtaining the precipitation data for Klang River Basin is the first step in computing the rainfall erosivity factor. The daily precipitation data from 2011 to 2020 was obtained from 22 rain gauge stations from DID, Malaysia. Based on the quantity of soil erosion, the R factor describes the precipitation intensity at a specific location. This factor is necessary for assessing the danger of soil erosion under changing future land uses and climatic conditions (Thapa, 2020). Compared to the other input parameters, this factor is the most crucial component of the RUSLE.

The annual precipitation was calculated by adding all the daily precipitation records from 2011 to 2020 of each station. The annual rainfall for each year (2011-2020) of each rain gauge station in the Klang River Basin was determined. The mean annual rainfall for the period of data collection (10 years) was calculated for each rain gauge station. Since the event-based precipitation data needed to calculate the storm duration of 30 minutes were not accessible at the rain gauge stations, the R factor was calculated for all the 22 selected rainfall gauge stations in the Klang River Basin using Equation 3.2 (Morgan, et al., 1984). Afterwards, the calculated R factor for each rain gauge station was inserted into ArcGIS to visually represent the R factor map. The Spatial Analyst tool in ArcGIS was utilized to interpolate all of the spatial data points of the R factor.

$$\mathrm{R} = 38.5 + 0.35\mathrm{P} \tag{3.2}$$

Where:
R = Rainfall erosivity factor
P = Mean annual rainfall in mm (2011-2020)

3.4.2 Soil Erodibility (K)

The K factor assesses the soil particle and susceptibility of soil types to separate and transit by precipitation and runoff. It is primarily influenced by soil texture, whereas the contribution of structure, organic matter, and permeability are also essential (Chadli, 2016). The characteristics of the soil influence this parameter.

The K factor values were computed for 4 distinct soil types within the Klang River Basin. An indication of the characteristics of soil particles for the separation and movement by precipitation is the erodibility of soils (Mengie, et al., 2022). For a specific soil type, the empirically determined K factor, which describes the physical and chemical characteristics of soil that influence its erodibility (Tirkey, et al., 2013). The K factor value was determined using Equations 3.3 to 3.7 proposed by Williams (1995). These equations were implemented to calculate the K factor for Klang River Basin:

$$\mathrm{K_{RUSLE}} = \mathrm{f_{csand}} \times \mathrm{f_{ci-si}} \times \mathrm{f_{orgC}} \times \mathrm{f_{hisand}} \tag{3.3}$$

Where:
$\mathrm{f_{csand}}$ = factor for soils with high coarse-sand contents

f_{cl-si} = factor for soils with high clay to silt ratios

f_{orgc} = factor for soils with high organic carbon content

f_{hisand} = factor for soils with extremely high sand contents

$$f_{csand} = \left(0.2 + 0.3 \times \exp\left[-0.256 \times m_s \times \left(1 - \frac{m_{silt}}{100}\right)\right]\right) \quad (3.4)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \quad (3.5)$$

$$f_{orgc} = \left(1 - \frac{0.25 \times orgC}{orgC + \exp[3.72 - 2.95 \times orgC]}\right) \quad (3.6)$$

$$f_{hisand} = \left(1 - \frac{0.7 \times \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + \exp\left[-5.51 + 22.9 \times \left(1 - \frac{m_s}{100}\right)\right]}\right) \quad (3.7)$$

Where:

m_s = % sand content

m_{silt} = % silt content

m_c = % clay content

orgC = % organic carbon content

3.4.3 Slope Length-Steepness (LS)

L factor and S factor, both obtained from DEM, are the two factors that comprise the LS factor. For the soil erosion modelling to calculate overland flow, this parameter is essential in RUSLE. Table 3.3 shows the value of m for the slope. LS factor was calculated by applying Equation 3.8.

$$LS = \left(\frac{X}{22.1}\right)^m (0.065 + 0.045S + 0.0065S^2) \quad (3.8)$$

Where:

X = slope length (m)

S = slope gradient (%)

m = varies from 0.2 to 0.5 depending upon the slope types (Table 3.3)

X was derived by multiplying flow accumulation and cell value, as shown in Equation 3.9. DEM was used to determine the values of X and S. After running fill and flow direction operations in ArcGIS, flow accumulation was extracted from the DEM to get the X value. When using a regression equation with fixed cell size, the input parameters flow accumulation and slope (%) are frequently used (Abdulkadir, et al., 2019).

$$\mathrm{X} = \text{Flow accumulation} \times \text{cell value} \tag{3.9}$$

Table 3.3: Value of m for Length and Steepness Factor of Slope (Wischmeier and Smith, 1978).

Slope (Percentage)	< 1	1–3	3–5	> 5
Value of m	0.20	0.30	0.40	0.50

3.4.4 Cover-Management (C)

Cropping and other techniques have an impact on erosion rates, reflected in the C factor. It is extremely sensitive since it tracks the dynamics of precipitation and plant growth. This factor is a non-dimensional number from 0 to 1 that correlates the comparable loss from continuous bare fallow to the soil loss caused by rainwater erosion under a specific ratio of soil loss and botanical conditions. The values of the C factor for various land use classes are summarized in Table 3.4. Therefore, to create the C-factor map of the research area, the land cover map was reclassified using these values. C factors were applied in the RUSLE model of the Klang River Basin.

Table 3.4: C Factor for Different Categories.

Class of land use	$\mathbf{C_{avg}}$	**Reference**
Water Bodies	0.01	Zainal, et al., 2021
Forest	0.003	Al-Quraishi, 2003
Vegetation	0.90	Al-Quraishi, 2003
Crops	0.24	Eisenberg and Muvundja, 2020
Built Area	0.0001	Al-Quraishi, 2003
Bare Ground	1	Vijith, Seling and Dodge-Wan, 2016
Clouds	0	Vijith, Seling and Dodge-Wan, 2016
Rangeland	0.38	Eisenberg and Muvundja, 2020

3.4.5 Support Practice (P)

Agricultural practice-based soil loss is indicated by the P factor. Three techniques, including terraces, crops, and contours, are essential for controlling erosion. The P factor has a value that ranges from 0 to 1. Values near 0 denote excellent conservation practices, while values near 1 denote weak conservation practices. The pre-determined P values that match the available land use categories were applied to construct the P factor map. Table 3.5 summarises the average values of P for each land cover class. P factors were applied in the RUSLE model of the Klang River Basin.

Table 3.5: Summary of P Factor for Different Types of Land Cover.

Types of land cover	P values	Reference
Water Bodies	0.50	Yusof, et al., 2019
Forest	0.1	Yusof, et al., 2019
Vegetation	0.50	Chadli, 2016
Crops	0.50	Al-Quraishi, 2003
Built Area	1.00	Al-Quraishi, 2003
Bare Ground	1.00	Zainal, et al., 2021
Rangeland	0.38	Taye, et al., 2017

3.5 Potential Erosion Map

The various data inputs processed by ArcGIS were used to generate maps of the five parameters: R, K, LS, C, and P. These raster data are combined using the RUSLE relation and the ArcGIS software to create a composite map of the estimated erosion loss in the research region. By using RUSLE model and potential erosion map, it can help to predict the annual soil erosion rates of Klang River Basin. Extreme occurrences like floods and additional destruction of the environment can be avoided by applying this method. Lastly, the annual soil erosion rate of Klang River Basin was assessed to identify the factor that has the greatest impact on soil erosion. The final output of the research was a soil susceptible map of the Klang River Basin. It was utilised to implement the necessary mitigation strategies to lessen soil erosion and river sedimentation as well as to protect the quality of the water in the river basin.

3.6 Summary

This chapter has presented the methodology to achieve the three objectives of the study. The description of data type was listed in Appendix A. Firstly, the climatic data for the precipitation, specific humidity, wind speed, air temperature, and soil moisture were collected from Giovanni. The soil moisture in Klang River Basin was examined in relation to meteorological and hydrological parameters by using correlation analysis to understand how these factors affect the soil moisture. Secondly, the annual soil erosion rate of Klang River Basin was predicted by integrating the RUSLE model with RS and GIS. The RUSLE factors were estimated accordingly using respective equations based on the data obtained from the rain gauge data, LULC map, soil map, and DEM. ArcGIS was implemented to create maps of RUSLE factors and composite maps of the estimated annual soil loss in the Klang River Basin. Lastly, the relationship between soil moisture and annual soil erosion rates in the Klang River Basin was compared based on the data obtained from Giovanni and RUSLE model. The results were used to determine how changes in soil moisture levels affect erosion rates and to identify areas of the river basin that are particularly susceptible to erosion. Effective soil conservation and management strategies were developed according to the relationship between soil moisture and soil erosion rates.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Firstly, the effect of different meteorological and hydrological parameters on soil moisture in Klang River Basin was discussed. Meteorological parameters such as precipitation, temperature, humidity, and wind speed were evaluated as they can affect soil moisture by influencing the amount of water available in the soil. The evaluation of these parameters was conducted on a monthly scale. Secondly, the annual soil erosion rate was evaluated by integrating the RUSLE model with remote sensing data in the GIS environment. Various factors such as R, K, LS, C, and P were collected to evaluate the annual soil erosion rate in Klang River Basin. Lastly, the relationship between soil moisture and the annual rates of soil erosion in the Klang River Basin was compared. Hazard management and mitigation measures for soil erosion were proposed based on the severity level of erosion.

4.2 Assessment of Meteorological and Hydrological Parameters on Soil Moisture in Klang River Basin

4.2.1 Effect of Precipitation on Soil Moisture

Precipitation and soil moisture are closely related as precipitation is the main source of water that replenishes the soil moisture. When it rains, the water percolates into the soil and increases its moisture content. As the soil moisture increases, it provides the necessary water for plants to grow and supports a healthy ecosystem.

The relationship between precipitation and soil moisture was represented using a scatter plot in Figure 4.1 and a double-line graph in Figure 4.2. The x-axis represents the amount of precipitation, while the y-axis of the graph represents the soil moisture content. Each data point on the graph represents the soil moisture content corresponding to a particular amount of precipitation.

According to Schober, et al. (2018), the magnitude and direction of a relationship between two variables are represented by correlation coefficients (CC). The CC between precipitation and soil moisture is 0.420. Therefore, the precipitation generally leads to an increase in soil moisture, and it is supported by the overall trend of a positive correlation pattern and a moderate correlation magnitude. The graph in Figure 4.1 typically shows an upward trend, indicating that as precipitation increases, the soil moisture content also increases. The moderate positive correlation pattern indicates that precipitation significantly influences soil moisture. The graph in Figure 4.1 illustrates that there is an upward trend between precipitation and soil moisture, indicating that as precipitation increases, the soil moisture content increases. However, the relationship between precipitation and soil moisture can be affected by other factors such as temperature, topography, and soil type, which may cause deviations from the general trend.

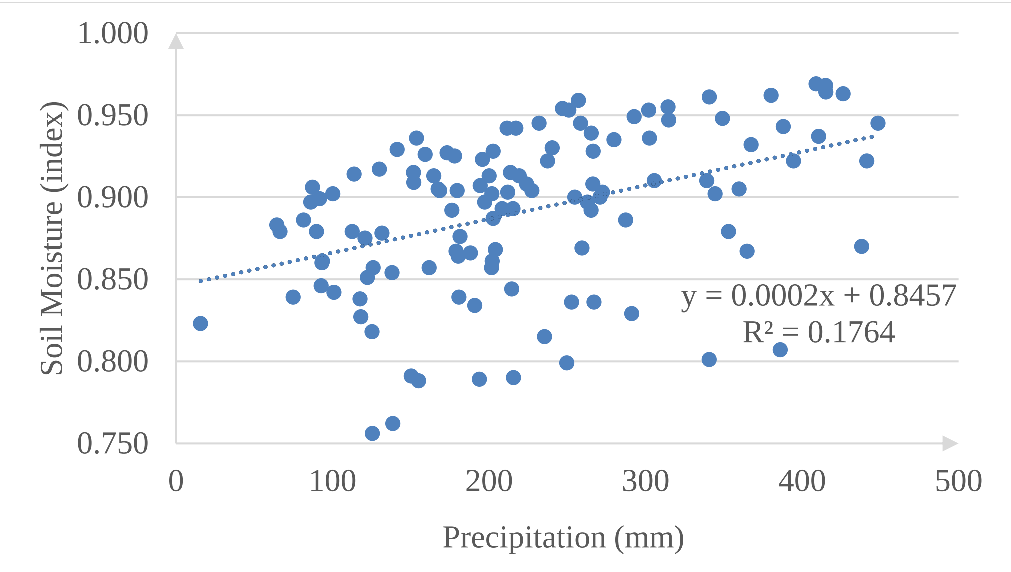

Figure 4.1: Soil Moisture vs Precipitation.

Figure 4.2 illustrates that the maximum mean monthly precipitation recorded in 2018 was 251.149 mm, and the corresponding mean monthly soil moisture was 0.906. The minimum mean monthly precipitation recorded in 2016 was 198.292 mm, and the corresponding mean monthly soil moisture was 0.864. The monthly soil moisture and precipitation data are illustrated in Appendices B and C. Based on the trend observed in Figure 4.2, it can be inferred that there is a positive relationship between precipitation and soil moisture. Specifically, when precipitation rises, there is a tendency for soil moisture to also increase.

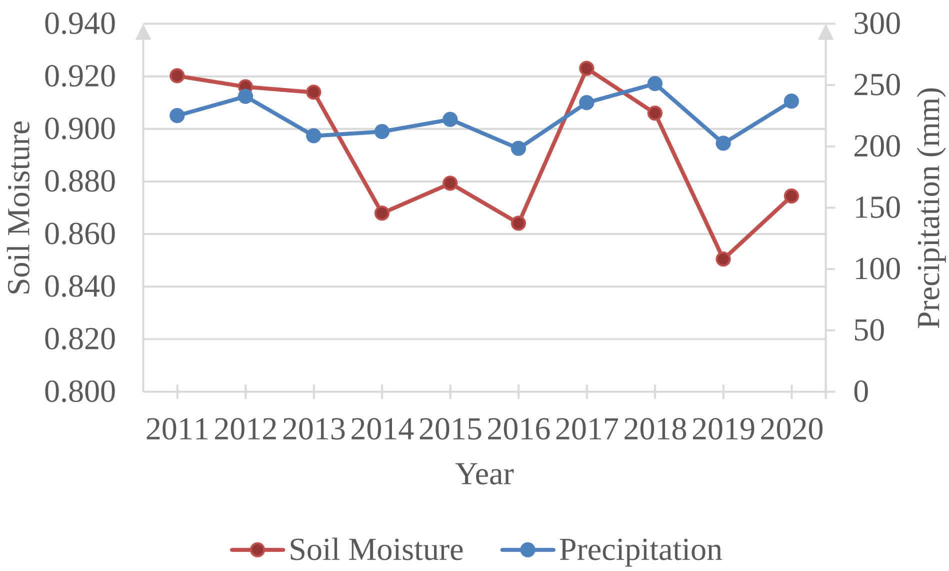

Figure 4.2: Relationship between Soil Moisture and Precipitation over a 10-year Period.

4.2.2 Effect of Specific Humidity on Soil Moisture

Specific humidity is a measure of the amount of water vapour present in the atmosphere, expressed as the mass of water vapour per unit mass of moist air. Soil moisture, on the other hand, refers to the amount of water held in the soil.

The relationship between specific humidity and soil moisture was represented using a scatter plot in Figure 4.3 and a double-line graph in Figure 4.4. The x-axis represents the specific humidity, while the y-axis of the graph represents the soil moisture content. Each data point on the graph represents the soil moisture content corresponding to the respective specific humidity.

The CC between specific humidity and soil moisture is 0.088. A CC of 0.088 indicates a very weak positive correlation. It indicates that specific humidity is not the main parameter influencing soil moisture levels. However, high specific humidity in the research area still contributes to an increase in soil moisture. It is supported by the overall trend of a positive correlation pattern and a very weak correlation magnitude. It indicates that the specific humidity has less influence on soil moisture than precipitation. The graph in Figure 4.3 illustrates a very small upward trend between specific humidity and soil moisture, indicating that as specific humidity increases, the soil moisture content increases.

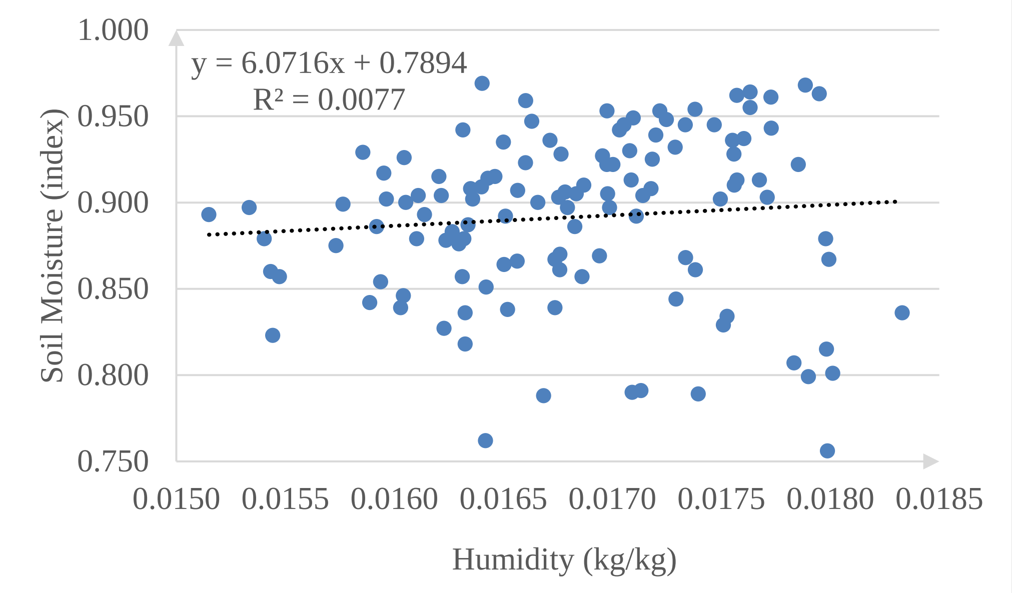

Figure 4.3: Soil Moisture vs Specific Humidity.

The effect of specific humidity on soil moisture can be indirect, as specific humidity is a critical factor in determining precipitation patterns, which in turn affect soil moisture levels. When specific humidity is high, it can lead to increased precipitation, which can replenish soil moisture levels. Conversely, when specific humidity is low, there may be a reduced amount of precipitation, leading to lower soil moisture levels. The rate at which moisture evaporates from the soil surface can be impacted by specific humidity and how it affects precipitation patterns. When the specific humidity is high, there is more water vapour in the atmosphere, which can decrease the evaporation rate from the soil surface and prolong the time that soil moisture is retained. Low specific humidity indicates that there is less water vapour in the atmosphere, which can speed up the rate of evaporation from the soil surface and result in lower soil moisture levels.

Therefore, if the correlation between specific humidity and soil moisture is weak, it suggests that other parameters at work are affecting soil moisture levels. However, it is evident that specific humidity has a crucial role in determining precipitation patterns and the evaporation rate, which can substantially impact soil moisture in Klang River Basin.

Figure 4.4 illustrates that the maximum mean monthly specific humidity recorded in 2020 was 0.0171 kg/kg, and the corresponding mean monthly soil moisture was 0.874. The minimum mean monthly specific humidity recorded in 2016 was 0.0166 kg/kg, and the corresponding mean monthly soil moisture was 0.864. The monthly data of soil moisture and specific humidity are illustrated in Appendices B and D. Based on the trend observed in Figure 4.4, it can be inferred that there is a positive relationship between specific humidity and soil moisture. Specifically, when specific humidity rises, there is a tendency for soil moisture also to increase.

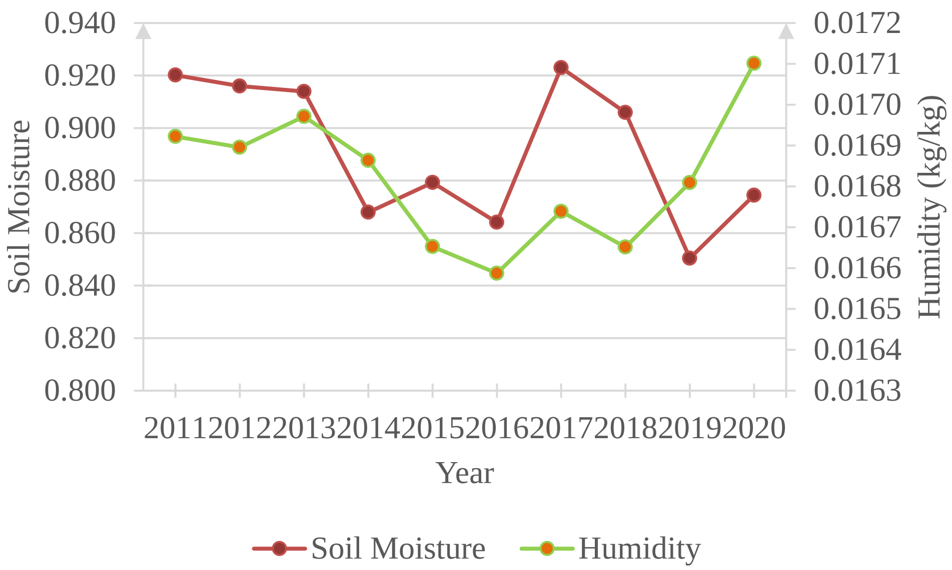

Figure 4.4: Relationship between Soil Moisture and Specific Humidity over a 10-year Period.

4.2.3 Effect of Wind Speed on Soil Moisture

The relationship between wind speed and soil moisture was represented using a scatter plot in Figure 4.5 and a double line graph in Figure 4.6. The x-axis represents the wind speed, while the y-axis of the graph represents the soil moisture content. Each data point on the graph represents the soil moisture content corresponding to the respective wind speed.

The CC between wind speed and soil moisture is -0.007. The graph in Figure 4.5 illustrates a very small downward trend between wind speed and soil moisture. A CC of -0.007 indicates a very weak negative correlation between wind speed and soil moisture. A negative correlation demonstrates that the wind speed increases, there is a slight tendency for soil moisture to decrease, and vice versa. However, the correlation is very weak, which indicates that the relationship between these two variables is not strong, and other meteorological parameters can be more influential in determining soil moisture levels.

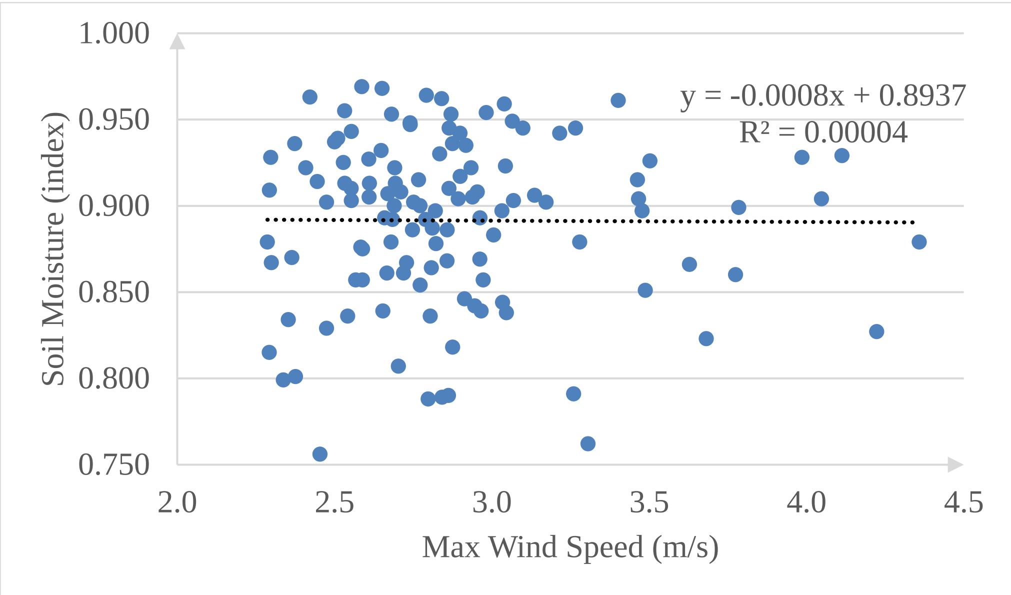

Figure 4.5: Soil Moisture vs Wind Speed.

A CC around 0 indicates that wind speed has a negligible effect on soil moisture. Although the effect of wind speed on soil moisture is negligible, wind speed can affect the rate of evaporation from the soil surface to control the soil moisture. High wind speeds can accelerate the rate of evaporation, causing a reduction in soil moisture levels. On the other hand, low wind speeds can hinder the rate of evaporation, which in turn can assist in preserving soil moisture levels.

In addition to affecting the rate of evaporation, wind can also impact soil moisture levels through its impact on plant transpiration. Transpiration can be influenced by wind speed. When wind speed is high, it can increase the rate of transpiration, leading to a reduction in soil moisture. Conversely, when wind speed is low, the rate of transpiration may be reduced, helping to maintain soil moisture levels.

Another way in which wind speed can affect soil moisture levels is through its impact on the distribution of precipitation. High wind speeds can lead to greater wind erosion, which can cause soil particles to be blown away and create dry patches in the soil. It can reduce the ability of the soil to absorb and retain moisture, leading to reduced soil moisture levels.

Generally, wind speed is the meteorological parameter that has a negligible impact on soil moisture. It particularly affects soil moisture through its impact on the rate of evaporation, plant transpiration and distribution of precipitation. Understanding the relationship between wind speed and soil moisture is important for managing agricultural systems, as well as for predicting and responding to drought conditions.

Figure 4.6 illustrates that the maximum mean monthly wind speed recorded in 2019 was 3.0189 m/s, and the corresponding mean monthly soil moisture was 0.850. The minimum mean monthly wind speed recorded in 2012 was 2.6633 m/s, and the corresponding mean monthly soil moisture was 0.916. The monthly data of soil moisture and wind speed are illustrated in Appendices B and E. After analysing the outcomes of these two parameters, it can be concluded that there is an inverse relationship between wind speed and soil moisture, implying that wind speed increases, the soil moisture tends to decrease.

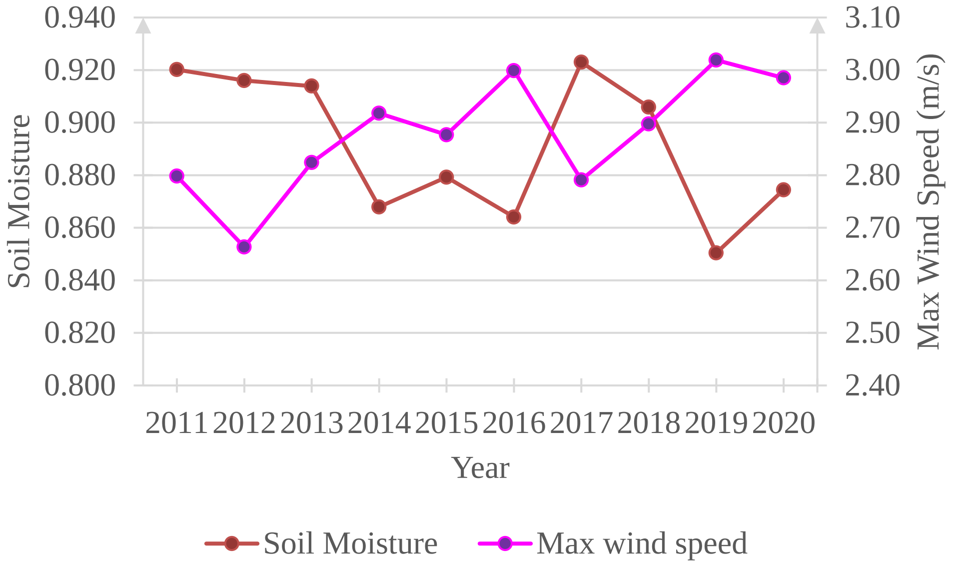

Figure 4.6: Relationship between Soil Moisture and Wind Speed over a 10-year Period.

4.2.4 Effect of Surface Air Temperature on Soil Moisture

The relationship between surface air temperature and soil moisture was represented using a scatter plot in Figure 4.7 and a double line graph in Figure 4.8. On the graph, the x-axis denotes the surface air temperature, and the y-axis corresponds to the soil moisture content. Every data point on the graph indicates the soil moisture content corresponding to the given surface air temperature.

The CC between surface air temperature and soil moisture is -0.664. The graph in Figure 4.7 illustrates a very strong downward trend between them. A CC of -0.664 indicates a strong negative correlation. A strong negative correlation indicates that when the surface air temperature increases, there is a strong tendency for soil moisture to decrease, and vice versa. It demonstrates that surface air temperature is a major parameter influencing soil moisture levels.

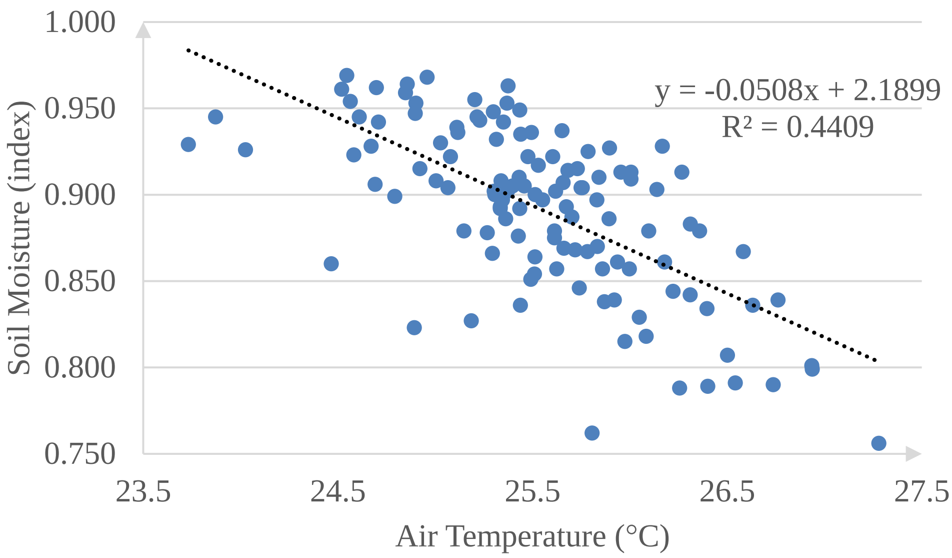

Figure 4.7: Soil Moisture vs Surface Air Temperature.

Surface air temperature has a significant effect on soil moisture levels. High temperatures can accelerate the evaporation rate, which causes the level of moisture in the soil to decrease. On the other hand, when surface air temperature drops, the rate of evaporation is reduced, which can aid in retaining soil moisture levels.

In addition to affecting the rate of evaporation, surface air temperature can also impact soil moisture levels through its impact on plant transpiration. Transpiration can be influenced by temperature. High temperatures can escalate the transpiration rate, resulting in decreased soil moisture levels. Conversely, lower temperatures can reduce the transpiration rate, which can aid in preserving soil moisture levels.

In general, the meteorological factor that significantly affects soil moisture is surface air temperature, particularly through its impact on the rate of evaporation and plant transpiration. Changes in surface air temperature will significantly affect the soil moisture and quality. Understanding the interaction between surface air temperature and soil moisture is important for managing soil resources and developing more effective conservation strategies for soil erosion.

Figure 4.8 illustrates that the maximum mean monthly surface air temperature recorded in 2019 was 25.9 ºC, and the corresponding mean monthly soil moisture was 0.850. The minimum mean monthly surface air temperature recorded in 2011 was 25.1 °C, and the corresponding mean monthly soil moisture was 0.920. The monthly data of soil moisture and surface air temperature are illustrated in Appendices B and F. After analysing the outcomes of these two parameters, it can be concluded that there is an inverse relationship between surface air temperature and soil moisture, implying that surface air temperature increases, the soil moisture tends to decrease.

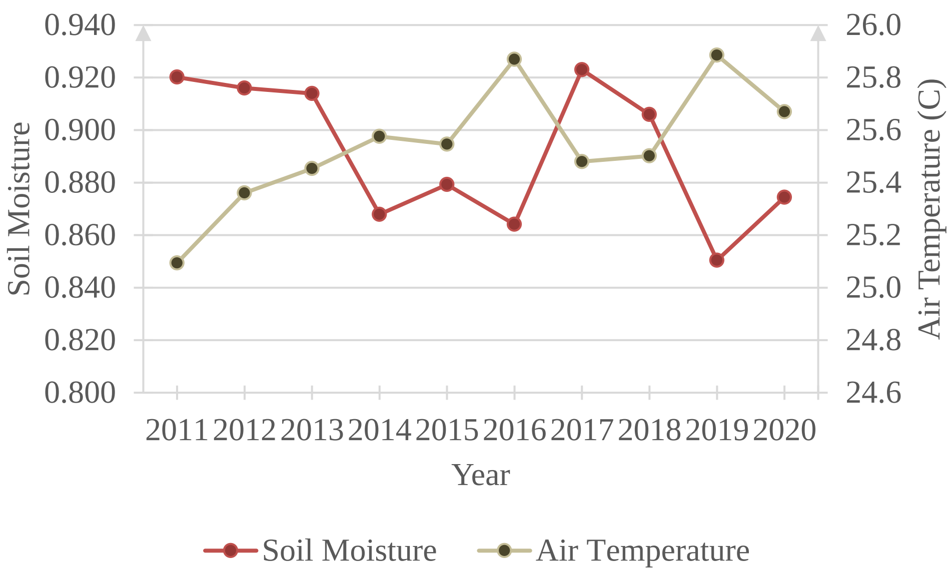

Figure 4.8: Relationship between Soil Moisture and Surface Air Temperature over a 10-year Period.

4.2.5 Relationship between Meteorological and Hydrological Parameters and Soil Moisture

The relationship between four different meteorological and hydrological parameters (precipitation, specific humidity, wind speed, and air temperature) with soil moisture of the Klang River Basin was first investigated. Figures 4.2, 4.4, 4.6 and 4.8 present the annual comparison between different climate parameters with soil moisture index. Table 4.1 shows the outputs of the correlation analysis based on the scale of CC in Appendix G. Among four climate parameters, precipitation and specific humidity show a positive correlation with soil moisture, with CC = 0.42 and 0.088, respectively. It indicates that an increase in precipitation or specific humidity will cause an increase in soil moisture content. On the other hand, wind speed and air temperature show a negative correlation with soil moisture, with CC = -0.007 and -0.664, respectively. It means that as wind speed or air temperature increases, the soil moisture decreases. Based on the correlation analysis, it can be deduced that the precipitation and air temperature influenced the soil moisture content the most in Klang River Basin, as the magnitude of the correlation analysis was higher.

Table 4.1: Correlation Analysis of Different Meteorological and Hydrological Parameters on Soil Moisture.

Parameter	**Precipitation**	**Humidity**	**Wind Speed**	**Air Temperature**
Correlation Coefficient	0.42	0.088	-0.007	-0.664
Relationship	Moderate Positive	Very Weak Positive	Very Weak Negative	Strong Negative

4.3 Assessment of the RUSLE Model on Annual Soil Erosion

4.3.1 Rainfall Erosivity (R)

R factor is the measure of the ability of rainfall to cause soil erosion based on the amount, intensity, and frequency of rainfall events. R factor is a numerical value assigned to each rainfall event based on intensity, duration, and frequency. The R factor is then used to estimate the total erosive power of rainfall in a given area over a given period. The RUSLE model uses the R factor to estimate the amount of soil loss due to water erosion. Table 4.2 shows the R factors calculated using precipitation data (2011-2020) from 22 rain gauge stations of DID. Between 2011 and 2020, the average annual precipitation for 22 rain gauge stations in the Klang River Basin ranged from 2094.85 mm to 3220.35 mm. The whole catchment area receives an average of 2658.90 mm of annual precipitation. The R factor of the Klang River Basin ranges from 771.76 to 1165.43 MJ mm ha^{-1} h^{-1} yr^{-1}, with its regional distribution shown in Figure 4.9. Research demonstrated that rainfall erosivity varies across the Klang River Basin. The results of the R factor analysis showed that the R factor was lower in the bottom region of the Klang River Basin when compared to the upper region of the Klang River Basin. The R value for the Klang River Basin was compared with other methods from Thailand, which yielded the results of 993 MJ mm ha^{-1} h^{-1} yr^{-1} (Harper, 1987).

Table 4.2: Annual Precipitation and R Factor of Rain Gauge Stations in Klang River Basin.

Station No	**Longitude**	**Latitude**	**Average Annual Precipitation (mm)**	**R Factor**
1	101.53	3.13	2094.85	771.70
2	101.88	3.04	2146.60	789.81
3	101.41	2.99	2245.70	824.49
4	101.50	3.02	2342.40	858.34
5	101.52	3.06	2278.60	836.01
6	101.80	3.10	2538.55	926.99
7	101.56	3.11	2889.55	1049.84
8	101.60	3.11	2889.85	1049.95
9	101.80	3.16	2160.75	794.76
10	101.87	3.17	2684.22	977.98
11	101.74	3.17	3065.60	1111.46
12	101.68	3.15	3086.25	1118.69
13	101.63	3.18	3220.35	1165.62
14	101.68	3.22	2974.80	1079.68
15	101.75	3.15	3121.55	1131.04
16	101.64	3.22	2273.60	834.26
17	101.73	3.27	2559.80	934.43
18	101.75	3.24	2732.00	994.70
19	101.71	3.24	2693.30	981.15
20	101.72	3.25	2658.60	969.01
21	101.67	3.08	3211.35	1162.47
22	101.77	3.37	2627.55	958.14

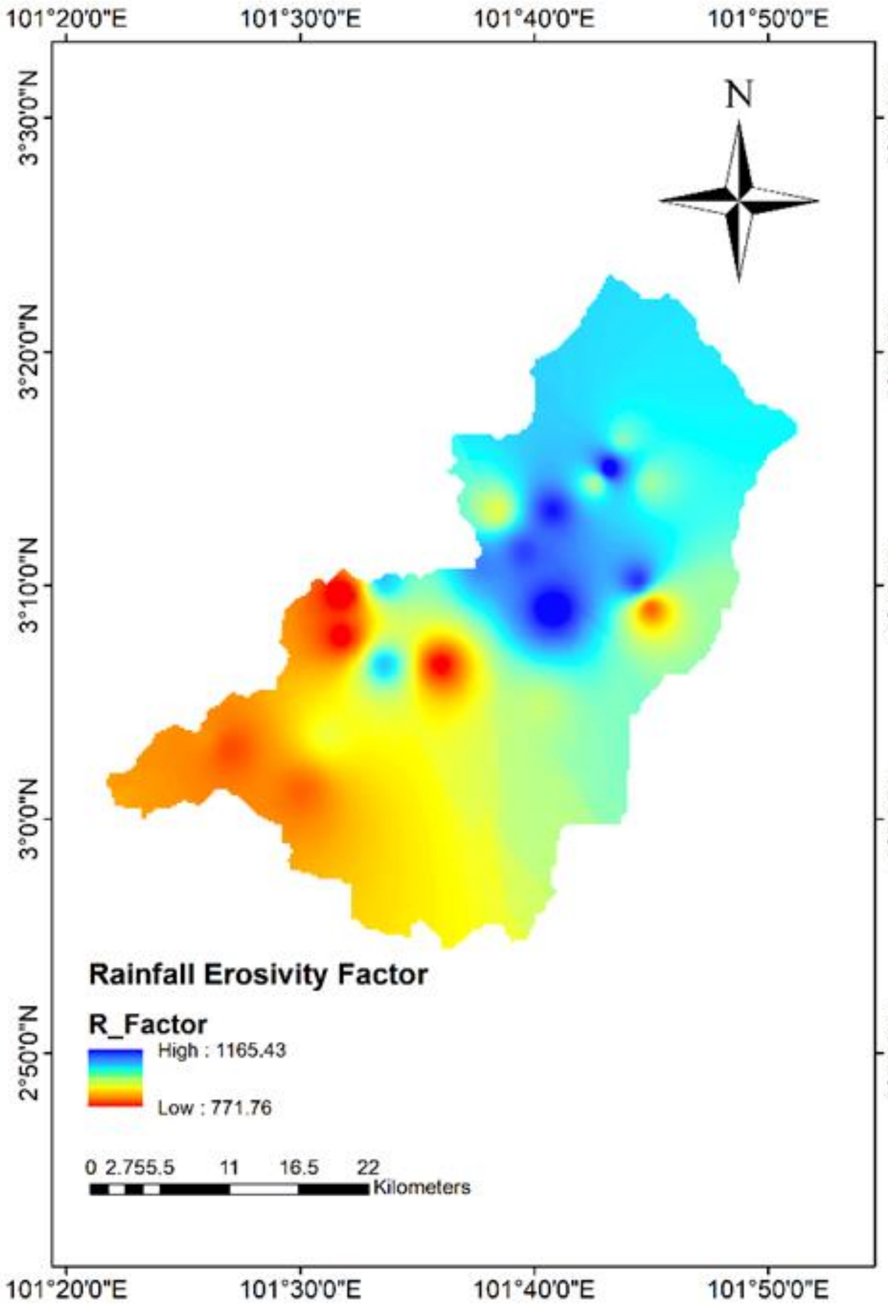

Figure 4.9: R Factor Map.

4.3.2 Soil Erodibility (K)

K factor map was developed from the soil property data such as the percentage of sand, silt, clay, and organic carbon content. These data were taken from the digital soil map (Geonetwork), prepared by FAO. Clay loam, clay, sandy clay loam and loam were the dominant soil types found in Klang River Basin. The composition of sand, silt, clay, and organic carbon content for each type of soil in the Klang River Basin is listed in Table 4.3. The distribution of different soil types is illustrated in Figure 4.10. The K values for the four soil types were calculated in Klang River Basin. By analysing the structure and texture of various types of soil, the map of soil erodibility is developed. The K factor map was generated using ArcGIS based on Equations 3.3 to 3.7. In Klang River Basin, 4 types of soil series with K factor values ranging from 0.11 to 0.13 ton h MJ^{-1} mm^{-1} were determined as illustrated in Figure 4.11. The majority of the soil types in the research region are clay loam and sandy clay loam, contributing to 76 % of the total land area. A low value of K factor (0.11 ton h MJ^{-1} mm^{-1}) was demonstrated in these regions of the Klang River Basin. K factors for clay and loam were 0.12 and 0.13 ton h MJ^{-1} $mm^{-1,}$ respectively. The silt fraction in this soil series is the major component to cause the increase in erosion susceptibility.

Table 4.3: Composition of Sand, Silt and Clay for Each Soil Type.

Soil Type	**Soil Unit Symbol**	**% of Sand**	**% of Silt**	**% of Clay**	**% of OC**
Clay Loam	AO	53.6	15.8	30.6	2.25
Clay	GE	42.8	20.4	36.8	1.3
Sandy Clay Loam	AO	53.6	15.8	30.6	2.25
Loam	OD	35	40	25	47.3

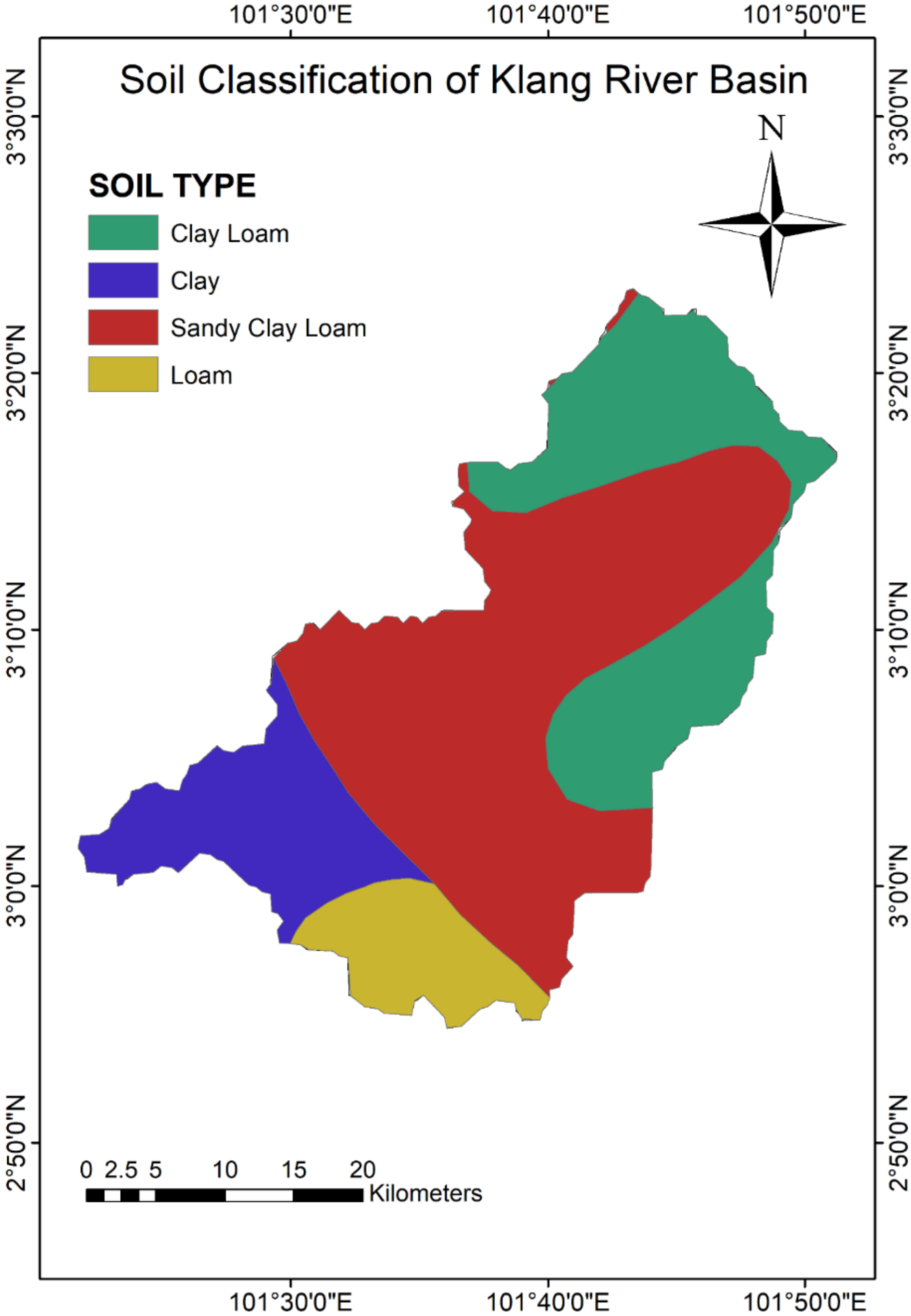

Figure 4.10: Soil Series Map.

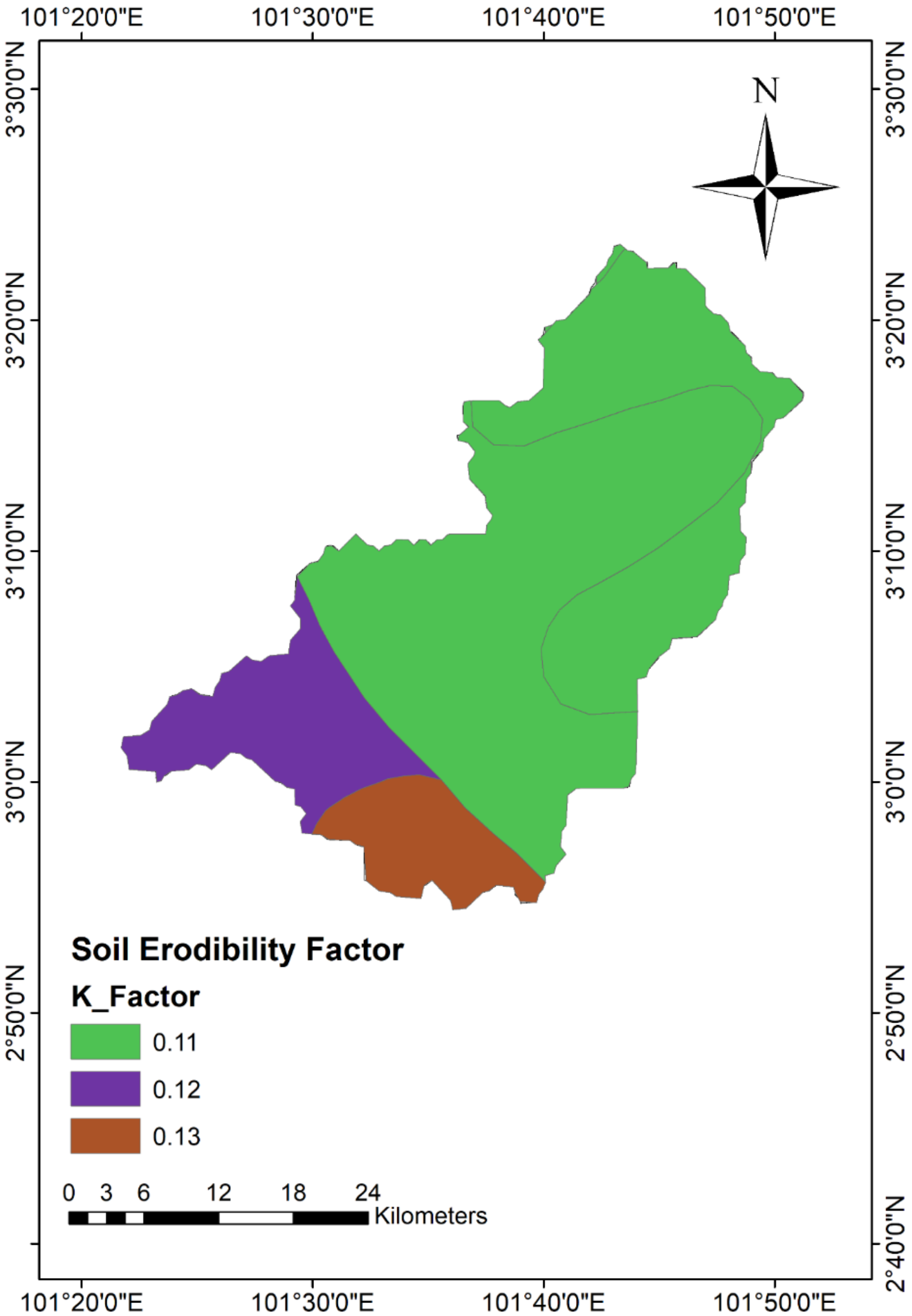

Figure 4.11: K Factor Map.

4.3.3 Slope Length-Steepness (LS)

LS factor in RUSLE combines two components, which are L and S. The slope length is the distance over which water flows on a field, and it is calculated based on the topography of the land. The slope steepness is calculated from the slope gradient of the land, which determines how easily the water can run off the land surface and erode the soil. The LS factor map was generated using

ArcGIS based on Equations 3.8 to 3.9. LS factor is computed using the flow accumulation, cell value and slope gradient (%) as inputs of Equation 3.8. The steeper the slope gradient, the higher the slope steepness factor, and the land is more susceptible to erosion. Figure 3.6 illustrates the Digital Elevation Model (DEM) of the Klang River Basin that can be used to determine the values of X and S in Equation 3.8. Figure 4.12 illustrates the percentage of slope steepness of the Klang River Basin. Since the overall slope steepness of Klang River Basin is more than 5 %, the value of m that is applied to determine the LS Factor is 0.50. Figures 4.13 and 4.14 show that the value of LS in the Klang River Basin ranges from 0 to 40.89. The investigation has also found that the class of LS factor ranging from 0 to 0.32 are present throughout the Klang River Basin, as illustrated in Figure 4.14. A minor portion of the study area exhibits an LS factor ranging from 0.32 to 40.89.

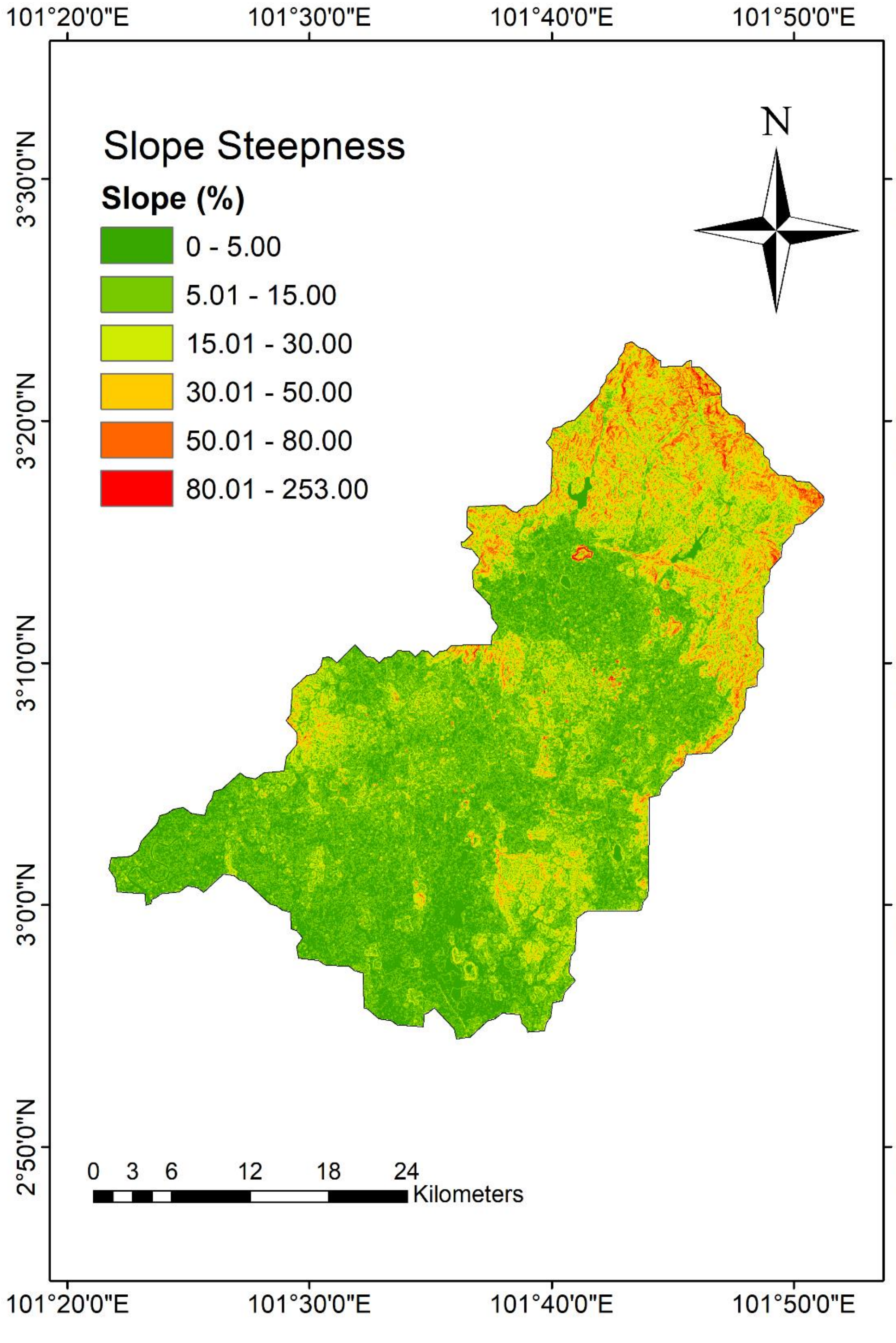

Figure 4.12: Slope Steepness (%) Map of Klang River Basin.

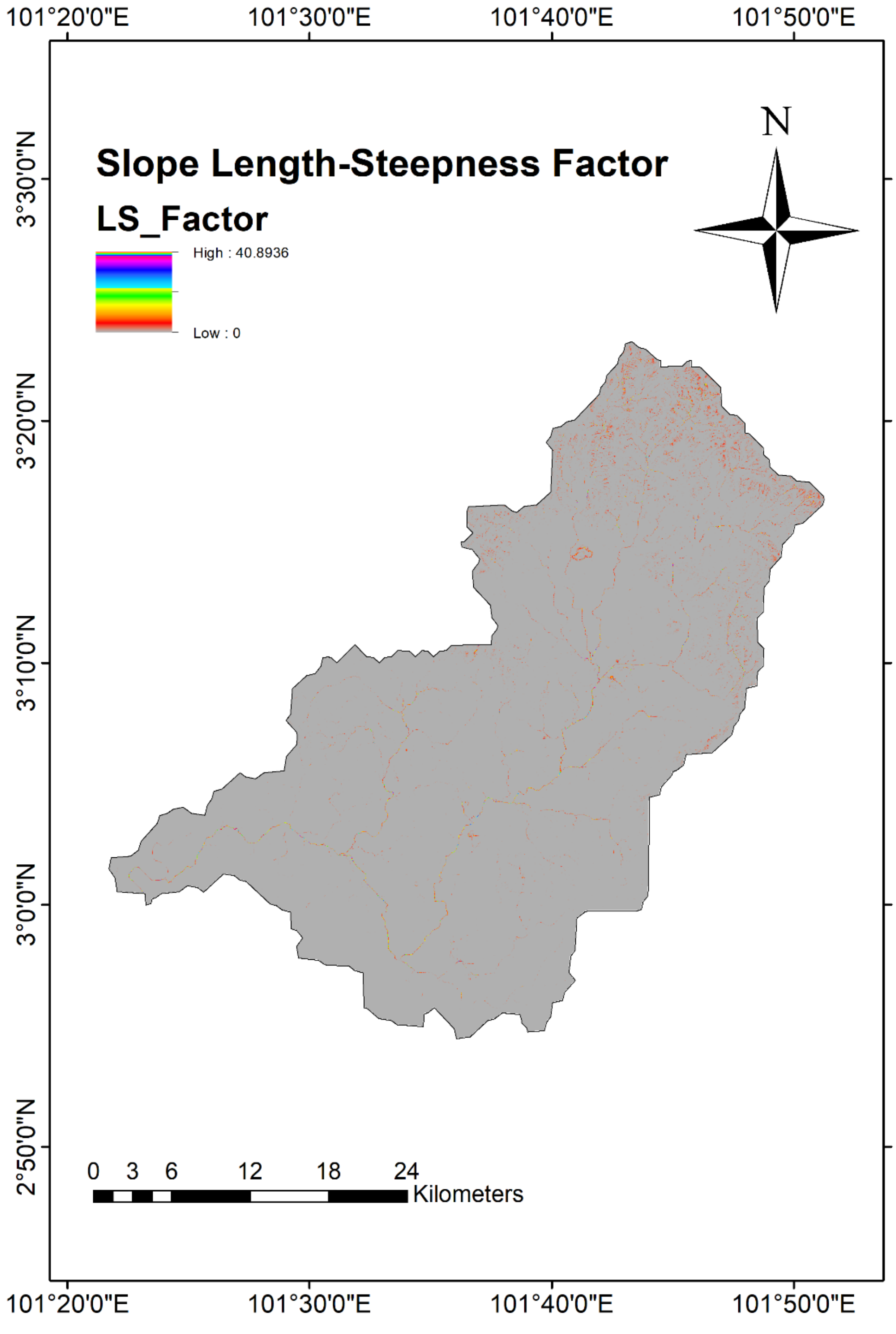

Figure 4.13: LS Factor Map (Range).

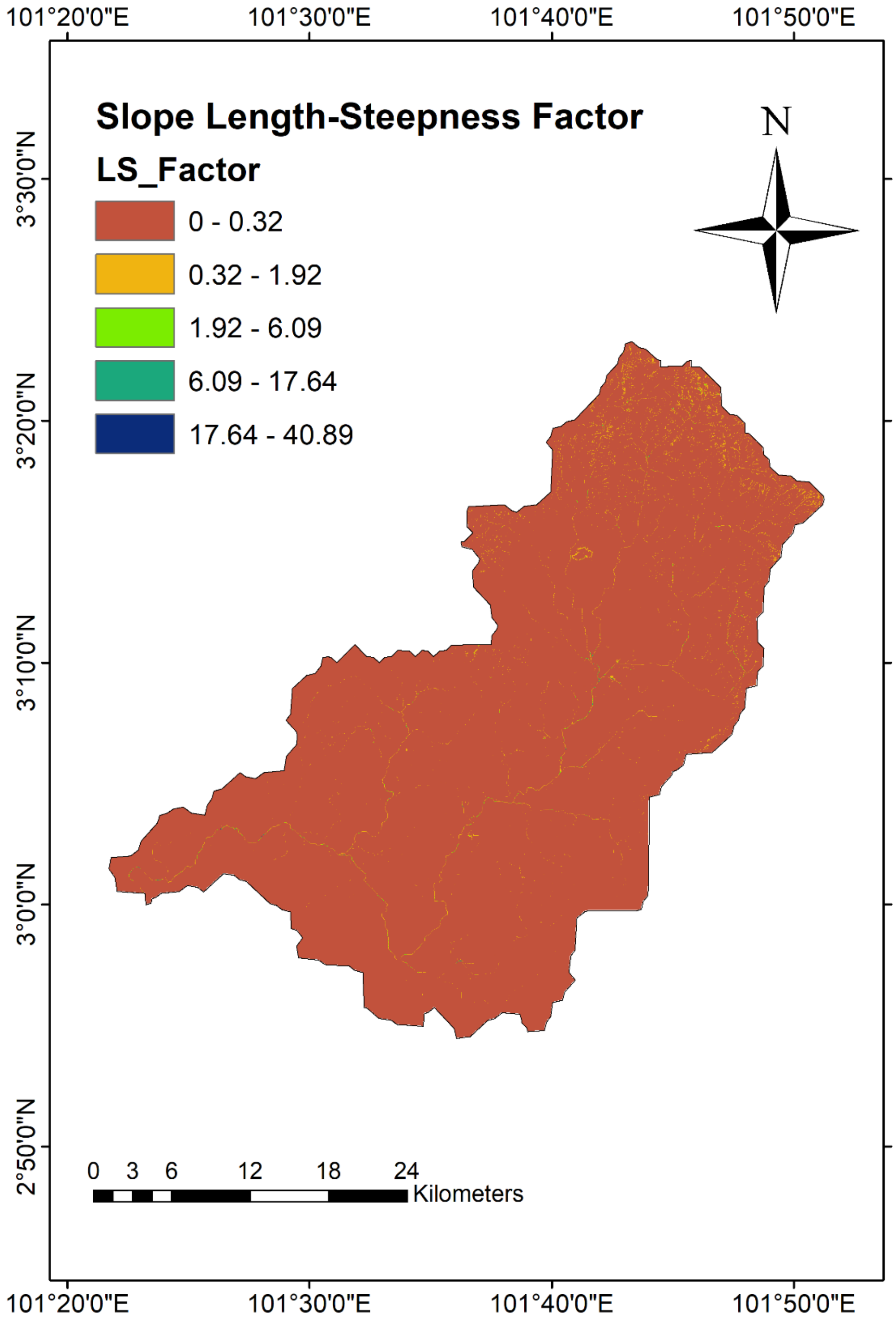

Figure 4.14: LS Factor Map (Classification).

4.3.4 Cover-Management (C)

According to the ESRI Sentinel-2 Land Cover Explorer 10m land use or land cover data (2020), the LULC map was plotted using ArcGIS 10.8 software, and it was illustrated in Figure 3.5. The ESRI Land Cover (10m) is actually the first reliable attempt to use Sentinel-2 to map the land cover at a resolution of 10 metres. Generally, it uses the highest spatial open data source, which has a considerably higher spatial resolution than the other land cover products, making it the greatest global land cover product currently available. A LULC map is divided into eight categories. It usually signifies that the map shows the different types of land use and land cover in a given area. The specific categories were used in the classification process of land use. Based on the ESRI Sentinel-2 Land Cover Explorer 10m land use or land cover data, water bodies, trees, vegetation, crops, built area, bare ground, clouds and rangeland were identified in Klang River Basin. For different categories of LULC, the corresponding C factors ranged from 0 for clouds to 1 for bare ground, as illustrated in Figure 4.15 and Table 4.4. The most extensive land use within the Klang River Basin is built area, accounting for 63.79 % of the entire research region. The highest C value of bare ground indicated that bare ground has the highest erosion risk while the lowest C value of clouds indicated that clouds have the lowest erosion risk.

Table 4.4: Classes of Land Use and Respective C Factor.

Land uses	**Coverage (%)**	**C Factor**
Water Bodies	2.49	0.01
Forest	30.72	0.003
Vegetation	0.02	0.9
Crops	0.59	0.24
Built Area	63.79	0.0001
Bare Ground	0.74	1
Clouds	0.02	0
Rangeland	1.62	0.38

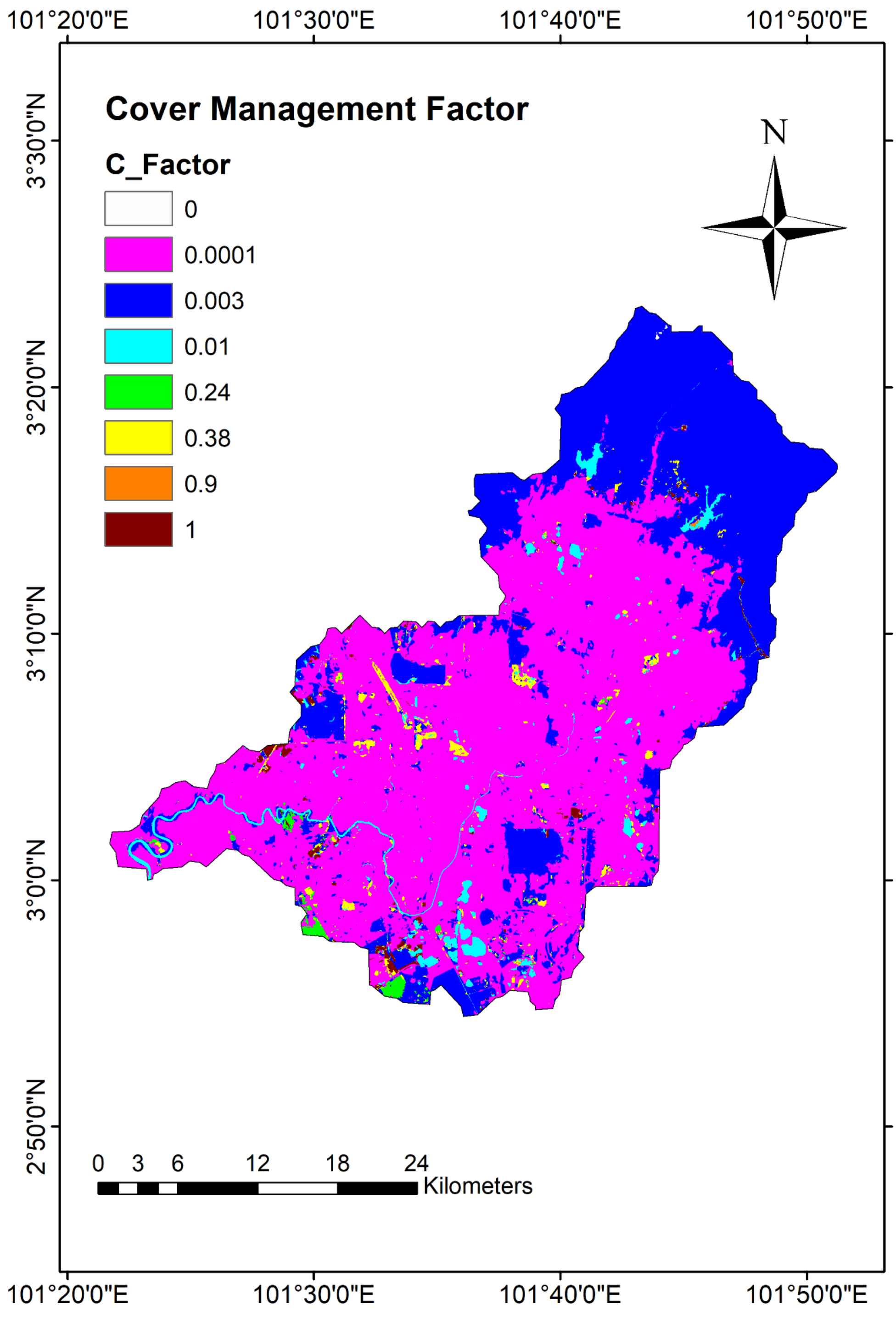

Figure 4.15: C Factor Map.

4.3.5 Support Practice (P)

According to the LULC map of the Klang River Basin (Figure 3.5), the basin is mainly comprised of urbanised zones. It indicates that the area has undergone significant development and human settlement. It can be shown in the red colour area in Figure 3.5. The support practice (P) factor of the Klang River Basin is generated from the LULC map of the basin, as illustrated in Figure 4.16 and Table 4.5. The P factor map shows that it varies between 0.1 and 1.0. The built area and bare ground, which have a P value of 1.0, comprise 63.79 % and 0.74% of the research area. Besides, the forested area covers a significant portion of the total land area, comprising around 30.72 % of the research area. The forested area has a P value of 0.1. P values for water bodies, vegetation and crops have been calculated to be 0.50. Rangeland is evenly distributed across the Klang River Basin, with a P value of 0.38.

Table 4.5: Classes of Land Use and Respective P Factor.

Land uses	**Coverage (%)**	**P Factor**
Water Bodies	2.49	0.5
Forest	30.72	0.1
Vegetation	0.02	0.5
Crops	0.59	0.5
Built Area	63.79	1
Bare Ground	0.74	1
Rangeland	1.62	0.38

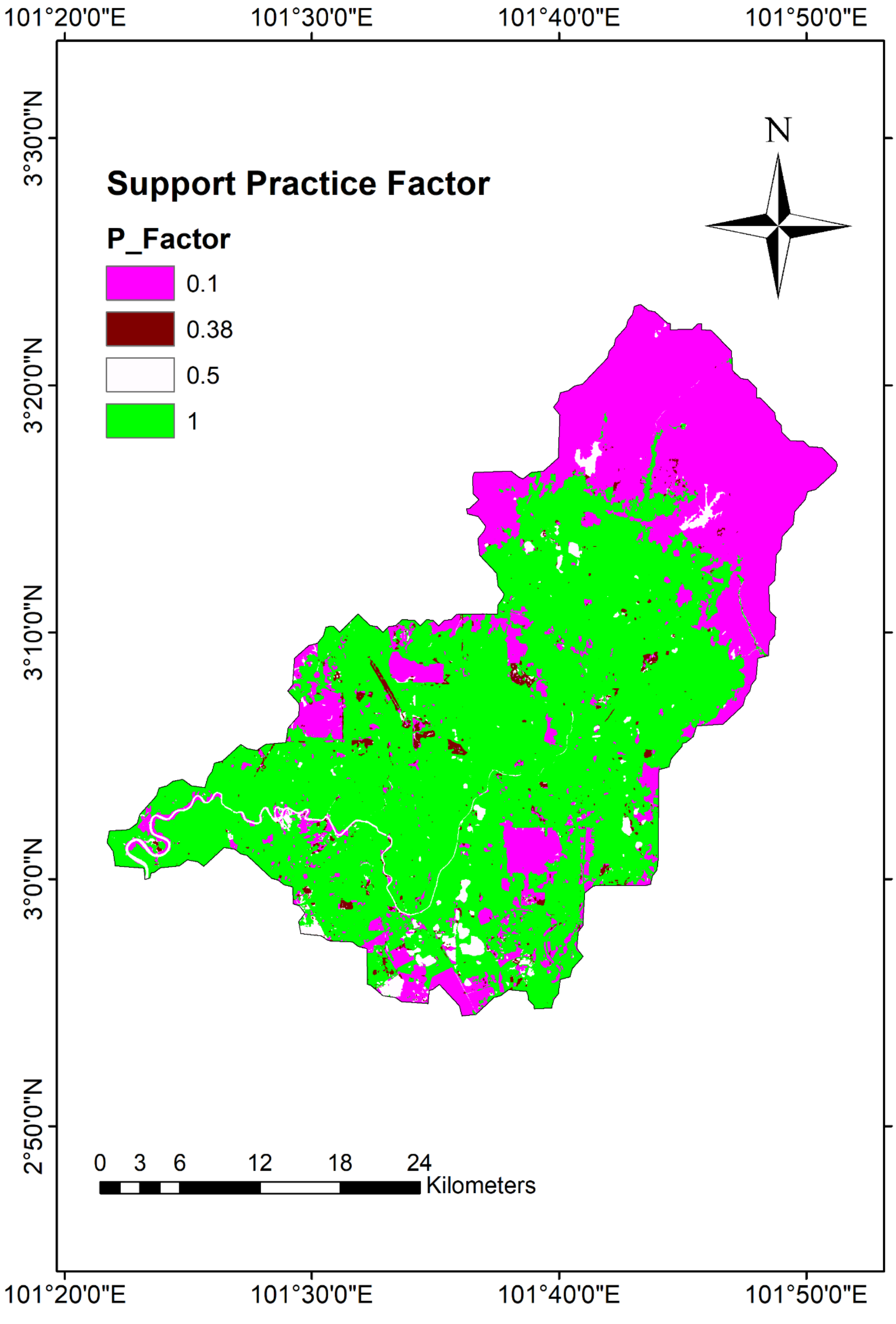

Figure 4.16: P Factor Map.

4.3.6 Estimation of Potential Annual Soil Erosion Rate

The average annual soil loss (A) was calculated using the RUSLE equation, which combines GIS and RS. Figure 4.17 demonstrates the utilization of the raster calculator function tool in ArcGIS to determine the average annual soil loss rate. It was achieved by multiplying the R, K, LS, C, and P factors discussed in the earlier chapter. The geographical distribution of annual soil erosion in the research area ranges from 0 to 300 tons ha^{-1} yr^{-1}, as illustrated in Figure 4.18. The overall soil erosion of the Klang River Basin is determined with a value of 476,134.1 tons yr^{-1}. The erosion rates of the Klang River Basin were divided into seven classes, as shown in Table 4.6. Many portions of the research areas in the Klang River Basin had a very low risk of erosion (less than 50 tons ha^{-1} yr^{-1}). Extreme to exceptional soil erosion only occurred in small areas of Klang River Basin due to steep slopes, intense rainfall, and extreme weather event. Table 4.7 shows the minimum, maximum, and mean values of different RUSLE factors in the Klang River Basin. Based on Table 4.7, the average values of R, K, LS, C and P factors are 966.92 MJ mm h^{-1} ha^{-1} year^{-1}, 0.12 ton h MJ^{-1} mm^{-1}, 0.014, 0.016 and 0.698 respectively.

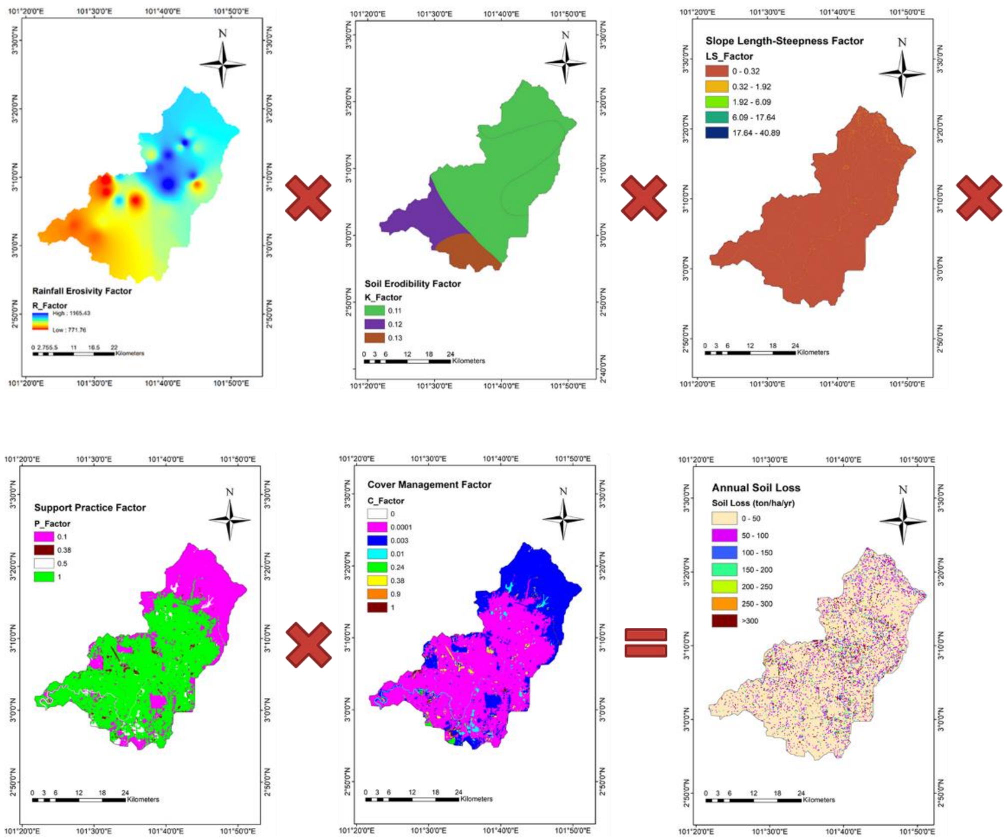

Figure 4.17: Calculation of Annual Soil Loss by using RUSLE Equation.

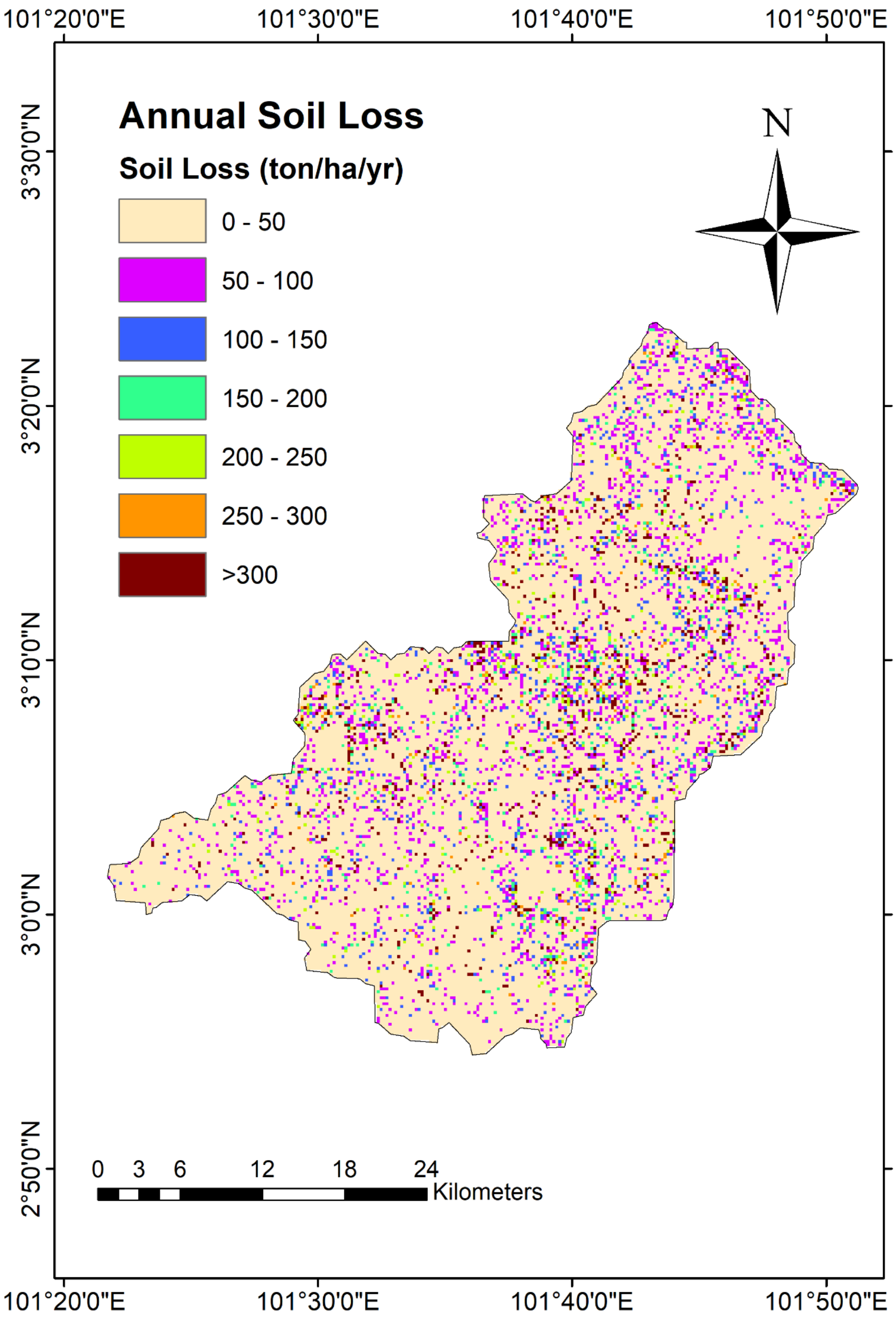

Figure 4.18: Average Annual Soil Loss Map in Klang River Basin.

Table 4.6: Categories of Soil Erosion based on Different Annual Soil Loss.

Annual Soil Loss (tons ha^{-1} yr^{-1})	Class of Erosion
0 – 50	Very Low
50 – 100	Low
100 - 150	Moderate
150 - 200	High
200 – 250	Severe
250 – 300	Extreme
> 300	Exceptional

Table 4.7: Values of Different RUSLE Factors.

Factor	Units	Min	Max	Mean
R	MJ mm h^{-1} ha^{-1} $year^{-1}$	771.76	1165.43	966.92
K	ton h MJ^{-1} mm^{-1}	0.11	0.13	0.12
LS	unitless	0.00	40.89	0.014
C	unitless	0.00	1.00	0.016
P	unitless	0.10	1.00	0.698

4.4 Relationship between Soil Moisture and Annual Soil Erosion

The RUSLE model is a widely used model for predicting soil erosion rates. The RUSLE model does not explicitly involve soil moisture as a consideration, but it can indirectly influence soil erosion rates by having an impact on these RUSLE parameters.

Firstly, the R factor in the RUSLE equation represents rainfall erosivity, which is a measure of the potential for rainfall to cause erosion. Higher rainfall intensity and frequency can increase the R factor, leading to higher erosion rates. However, soil moisture can affect the erosivity of rainfall by altering the soil's ability to absorb water. According to Moragoda, et al. (2022), to determine soil erosion resistance, it is crucial to consider not only the spatial differences in soil moisture but also the temporal fluctuations in soil moisture, including before, during, and between rain events. When soil is dry, it has less capacity to absorb water, and as a result, rainfall events can cause more runoff and erosion. This is because the soil cannot hold the water, and the excess water flows over the surface, picking up sediment particles and carrying them away. On the other hand, when the soil is wet, it has more capacity to absorb water, and the water can infiltrate into the soil more efficiently, reducing the amount of runoff and erosion. Wet soil also provides more resistance to the erosive forces of rainfall, as the water can be absorbed by the soil and held in place, reducing the velocity of the runoff and preventing sediment from being carried away. Therefore, soil moisture is an important factor in determining the erosivity of rainfall and its impact on soil erosion.

Secondly, K factor, which is a measure of how easily soil can be eroded, is influenced by soil texture, structure, and organic matter content. Soil moisture can affect the erodibility of soil by altering its physical properties. Soil moisture can affect these factors by affecting soil aggregation, porosity, and nutrient availability. When the soil is too dry, it can become more susceptible to erosion due to reduced soil aggregation and structure. At the same time, too much moisture can lead to soil compaction and reduced pore space, making it more susceptible to erosion (Li, et al., 2022).

In addition, according to Benavidez, et al. (2018), soil moisture can also affect the C factor in RUSLE. When the soil moisture is low, plants have difficulty growing and maintaining cover, reducing their ability to protect the soil from erosion. On the other hand, when the soil moisture is high, vegetation cover will also become less effective in preventing soil erosion due to increased runoff and saturation of the soil.

Although soil moisture is not a direct factor in the RUSLE model, it can indirectly affect soil erosion rates through its effects on rainfall erosivity, soil erodibility, vegetation cover, etc. To accurately predict soil erosion rates using the RUSLE model, it is important to consider the combined impact of all the relevant factors, including soil moisture. Proper soil management, such as maintaining healthy vegetation cover and avoiding overgrazing or excessive tillage, can help to minimize erosion and maintain healthy soil moisture levels.

4.5 Summary

In the research, an assessment was conducted to study the impact of meteorological and hydrological parameters on soil moisture. The research evaluated the data such as precipitation, specific humidity, wind speed, surface air temperature, and soil moisture from the satellite in Klang River Basin over a 10-year period on a monthly basis. Secondly, to forecast soil erosion rates based on variables including rainfall, slope, soil type, and land use, the RUSLE model is frequently utilised. The results of the findings demonstrated how well the RUSLE model predicted annual soil erosion rates in Klang River Basin. The research also discovered that the R and LS factors had the most significant impact on soil erosion rates, while the K factor, C and P factors had a lesser impact. Lastly, although soil moisture is not a direct factor in the RUSLE model, it can indirectly affect soil erosion rates through its effects on rainfall erosivity, soil erodibility, vegetation cover, etc. It is important to consider the combined impact of all the relevant factors, including soil moisture. It shows that controlling these factors, such as using conservation techniques to lessen runoff, could be a successful strategy for reducing soil erosion.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In conclusion, precipitation and specific humidity are the two possible factors that may lead to soil erosion, as they will increase the soil moisture content, which can change the weight of the soil and reduce its stability, making it prone to erosion. The RUSLE model was developed to assess annual soil erosion, and it can be applied at the local or regional level. The RUSLE model combines all erosion metrics from the RS and GIS frameworks to identify erosion-prone zones quickly. The RUSLE model is developed based on five factors, i.e. R, K, LS, C, and P. Based on the RUSLE model developed for Klang River Basin, most of the study areas in Klang River Basin have a very low risk of erosion (< 50 tons ha^{-1} yr^{-1}). About 30 % of the study area has a significant risk of erosion. The research can be used as a guide for soil conservation and management in Klang River Basin.

For objective 1, which is "to investigate the effect of different meteorological and hydrological parameters on soil moisture in Klang River Basin", the conclusion can be summarised as follows:

1. The climatic data of meteorological and hydrological parameters such as precipitation, specific humidity, wind speed, surface air temperature, and soil moisture were obtained from NASA Giovanni.
2. Precipitation and specific humidity show a positive correlation with soil moisture, with CC = 0.42 and 0.088, respectively. This indicates that an increase in precipitation or specific humidity will cause an increase in soil moisture content.
3. Wind speed and surface air temperature show a negative correlation with soil moisture, with CC = -0.007 and -0.664, respectively. This indicates that soil moisture content decreases as wind speed and surface air temperature increases.

4. Based on the correlation analysis, it can be deduced that the precipitation and surface air temperature influenced the soil moisture content the most in Klang River Basin.

For objective 2, which is “to predict the annual soil erosion rate by integrating the RUSLE model with remote sensing data in the GIS environment”, the conclusion can be summarised as follows:

1. Precipitation data from 2011 to 2020 were obtained from 22 rain gauge stations from DID, Malaysia. LULC map of Klang River Basin was obtained from the ESRI Sentinel-2 Land Cover Explorer at 10m resolution. The soil type map was retrieved from FAO, and DEM was obtained from USGS Earth Explorer.
2. The geographical distribution of average annual soil erosion in the research area ranges from 0 to 300 tons ha^{-1} yr^{-1}. The overall soil erosion of the Klang River Basin is determined with a value of 476,134.1 tons yr^{-1}.
3. Many portions of the research areas in the Klang River Basin had a very low risk of erosion (less than 50 tons ha^{-1} yr^{-1}). Extreme to exceptional soil erosion only occurred in small areas of the Klang River Basin.

For objective 3, which is “to compare the relationship between soil moisture and annual rates of soil erosion in the Klang River Basin”, the conclusion can be summarised as follows:

1. When soil moisture is too low, the soil becomes more susceptible to erosion because the lack of moisture reduces the cohesive strength of the soil.
2. When soil moisture is too high, the soil becomes saturated, and the excess water can increase the weight of the soil and reduce its stability, making it more prone to erosion.

5.2 Recommendations

5.2.1 Soil Erosion Hazard Management and Mitigation Strategies

Soil erosion is a serious environmental problem that can result in land degradation, decreased soil productivity, and increased sedimentation in Klang

River Basin. To prevent and mitigate soil erosion, it is essential to estimate the level of erosion and assess the potential hazards associated with it. A successful method to determine erosion-prone locations and evaluate the possible environmental impacts of soil erosion is creating a soil erosion hazard map. This map can assist in land-use planning decisions, enabling the adoption of soil erosion risk management and mitigation measures.

The findings from this research can serve as fundamental information to aid in conservation management and land-use planning. Additionally, the methods employed in this research are reliable for overall planning and evaluation objectives, which can facilitate the recognition of regions in the Klang River Basin that are prone to soil erosion. Policymakers and land managers can utilise the soil erosion hazard map when it has been created to establish guidelines on land-use planning and management. For instance, high-risk erosion zones of the Klang River Basin can be designated for conservation or reforestation. In contrast, low-risk areas of the Klang River Basin can be used for agricultural or urban expansion. Management efforts should be primarily focused on areas in the Klang River Basin with severe and extreme hazard levels due to soil erosion. These areas are predominantly found in regions with close to urban areas, low to moderate slope steepness and altitude, and in bare land areas with extremely low vegetation coverage. Table 5.1 illustrates several general hazard management and mitigation techniques for soil erosion based on the severity level of erosion.

Table 5.1: General Hazard Management and Mitigation Techniques for Soil Erosion.

Class of Erosion	Annual Soil Loss (tons ha^{-1} yr^{-1})	General Management and Mitigation Techniques
Very Low to Low	0 – 100	- It is necessary to prevent any additional erosion. Plant vegetation cover such as grasses, shrubs, or trees to stabilize the soil and reduce erosion (Rahman, et al., 2009). - Reduce tillage or no-till farming practices to prevent soil disturbance and maintain soil structure (Ogunsola, et al., 2020). - Avoid leaving bare soil exposed for extended periods by using cover crops or crop rotation (Quintarelli, et al., 2022).
Moderate to High	100 – 200	- It is important to adhere to appropriate crop rotation practices and maintain an appropriate cropping pattern. Additionally, it is crucial to plan for the regeneration of damaged vegetation. Before authorizing the construction of any new infrastructure, it is necessary to conduct an Environmental Impact Assessment (EIA) (Rahman, et al., 2009). - Use conservation tillage practices such as minimum tillage, making use of less harmful tillage equipment, and strip-tillage to reduce soil disturbance and prevent soil erosion (Ogunsola, et al., 2020). - Construct sediment basins, sediment traps, or sediment ponds to capture sediment and prevent it from entering nearby waterways (Minnesota Pollution Control Agency, 2023).
Severe to Extreme	200 – 300	- Immediate attention should be directed towards soil conservation as a top priority. When designing conservation plans, emphasis should be placed on agronomic measures of soil conservation, such as conservation tillage, to mitigate severe soil erosion and safeguard vulnerable areas (Rahman, et al., 2009). - Use extreme conservation practices such as no-till farming, cover crops, or agroforestry to maintain soil structure and reduce erosion (Ogunsola, et al., 2020). - Implement stormwater management systems such as infiltration basins, permeable pavements, or rain gardens to reduce water runoff and prevent erosion (Robinson, 2019).

Table 5.1: Continued

Exceptional	> 300	- Apply emergency erosion control measures such as installing erosion control blankets, sediment fences, or sandbags to prevent immediate erosion. - Use erosion control engineering measures such as slope stabilization, gully reshaping, or channel stabilization to restore eroded areas (Frankl, et al., 2020). - Implement long-term erosion control measures such as afforestation, agroforestry, or land conservation to prevent further erosion and improve soil health (Singh, et al., 2020). - It is recommended to employ additional engineering structures aimed at controlling soil erosion. These may include terraces, contour bandings or hedgerows, and channel stabilization (Rahman, et al., 2009).

5.2.2 Suggestions for Improving Future Research

Based on the integration of the RUSLE model with RS data in the GIS environment for studying the annual soil erosion rate, the following are some recommendations that can be considered to improve future studies:

1. To improve the accuracy of the results, meteorological and hydrological data from a longer study period (more than 10 years) might be collected, gathered, and further characterised.
2. A finer temporal resolution, such as an hourly assessment, can be conducted in the data collection of meteorological and hydrological parameters because hourly evaluations can offer more specific information on changes that take place over shorter time frames.
3. The RUSLE model must be validated to ensure that the RUSLE model can reliably forecast soil erosion rates. The RUSLE model must be tested using field measurements before merging it with remote sensing data is crucial.
4. Comparing the results of the RUSLE model against those obtained from other methods or approaches, such as the USLE and MUSLE model, is advised to assess the performance of the RUSLE model and the degree to which it can be integrated with remote sensing data.
5. To increase the precision of the findings, it is advised to include field observations in addition to remote sensing data. This may involve taking measurements of soil erosion rates in the field as well as other parameters, including land use and cover.
6. The resolution of the data affects how accurately remote sensing findings are generated. Consequently, it is advised to employ high-resolution remote sensing data to enhance the accuracy of the results, including aerial or satellite imagery.

It is significant to remember that the RUSLE model, which is susceptible to numerous sources of error and uncertainty, is a simplified portrayal of the intricate processes that control soil erosion. As a result, rather than serving as a precise forecast of soil erosion rates, it should be utilised as a tool to guide decision-making.

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APPENDICES

Appendix A: Description of Data Type.

Data Type	Dataset	Spatial	Source
Soil Moisture	MERRA-2 Model	0.625º	https://giovanni.gsfc.nasa.gov/giovanni/
Precipitation	GPM-IMERG	0.1º	https://giovanni.gsfc.nasa.gov/giovanni/
Specific Humidity	GLDAS Model	0.25º	https://giovanni.gsfc.nasa.gov/giovanni/
Wind Speed	MERRA-2 Model	0.625º	https://giovanni.gsfc.nasa.gov/giovanni/
Surface Air Temperature	MERRA-2 Model	0.625º	https://giovanni.gsfc.nasa.gov/giovanni/
Rain Gauge Data	-	-	Drainage and Irrigation Department (DID), Malaysia
Land Use/Land Cover (LULC) Map	-	-	Esri | Sentinel-2 Land Cover Explorer
Soil Type Map	-	-	Food and Agriculture Organization (FAO)
Digital Elevation Model (DEM)	-	-	https://earthexplorer.usgs.gov/

Appendix B: Monthly Surface Soil Moisture (index) from 2011 to 2020.

Month	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	0.945	0.923	0.942	0.929	0.926	0.904	0.947	0.969	0.904	0.866
Feb	0.906	0.930	0.945	0.823	0.860	0.879	0.915	0.899	0.851	0.827
Mar	0.908	0.939	0.913	0.762	0.836	0.791	0.892	0.869	0.788	0.789
Apr	0.922	0.925	0.903	0.815	0.829	0.756	0.910	0.844	0.799	0.807
May	0.927	0.913	0.928	0.867	0.834	0.801	0.913	0.879	0.790	0.836
Jun	0.914	0.879	0.883	0.839	0.857	0.839	0.909	0.907	0.861	0.868
Jul	0.886	0.878	0.875	0.842	0.846	0.857	0.917	0.902	0.861	0.910
Aug	0.892	0.876	0.854	0.864	0.904	0.857	0.942	0.879	0.838	0.897
Sep	0.902	0.893	0.908	0.867	0.887	0.893	0.935	0.900	0.818	0.903
Oct	0.922	0.905	0.900	0.902	0.886	0.897	0.915	0.922	0.870	0.905
Nov	0.964	0.963	0.955	0.943	0.937	0.936	0.945	0.948	0.897	0.932
Dec	0.954	0.968	0.961	0.962	0.949	0.959	0.936	0.953	0.928	0.953
Average	**0.920**	**0.916**	**0.914**	**0.868**	**0.879**	**0.864**	**0.923**	**0.906**	**0.850**	**0.874**

Appendix C: Monthly Accumulated Precipitation (mm) from 2011 to 2020.

Month	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	258.579	195.876	217.303	141.430	159.334	168.598	314.909	409.108	179.776	188.257
Feb	87.351	240.485	232.133	15.780	93.401	112.716	151.810	91.832	122.442	118.159
Mar	266.412	265.372	164.828	138.660	252.796	150.446	265.278	259.493	155.081	193.926
Apr	237.487	178.071	212.081	235.542	291.278	125.608	305.661	214.620	249.742	386.169
May	173.335	219.441	202.765	365.025	191.034	340.730	200.214	353.137	215.705	267.163
Jun	113.934	66.583	64.558	74.940	161.898	180.896	152.080	194.440	202.099	204.155
Jul	81.598	131.722	120.868	101.018	92.842	201.725	130.044	100.333	93.676	339.203
Aug	176.414	181.601	138.133	180.509	227.471	126.070	211.662	89.902	117.739	86.153
Sep	201.923	208.484	224.114	179.043	202.766	215.435	279.899	254.926	125.388	272.570
Oct	441.490	359.896	271.078	344.593	287.389	197.365	213.829	394.629	438.226	167.626
Nov	415.251	426.312	314.542	388.077	410.687	302.635	448.658	349.281	262.927	367.569
Dec	247.056	415.235	340.859	380.323	292.827	257.281	153.795	302.088	266.640	251.104
Average	**225.069**	**240.757**	**208.605**	**212.078**	**221.977**	**198.292**	**235.653**	**251.149**	**202.453**	**236.838**

Appendix D: Monthly Specific Humidity (kg/kg) from 2011 to 2020.

Month	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	0.0171	0.0166	0.0170	0.0159	0.0160	0.0171	0.0166	0.0164	0.0161	0.0166
Feb	0.0168	0.0171	0.0175	0.0154	0.0154	0.0163	0.0165	0.0158	0.0164	0.0162
Mar	0.0172	0.0172	0.0176	0.0164	0.0163	0.0171	0.0171	0.0169	0.0167	0.0174
Apr	0.0179	0.0172	0.0177	0.0180	0.0175	0.0180	0.0176	0.0173	0.0179	0.0178
May	0.0170	0.0171	0.0176	0.0180	0.0175	0.0180	0.0177	0.0180	0.0171	0.0183
Jun	0.0164	0.0161	0.0163	0.0167	0.0169	0.0160	0.0164	0.0166	0.0174	0.0173
Jul	0.0159	0.0162	0.0157	0.0159	0.0160	0.0163	0.0160	0.0160	0.0168	0.0169
Aug	0.0165	0.0163	0.0159	0.0165	0.0162	0.0155	0.0163	0.0154	0.0165	0.0168
Sep	0.0164	0.0161	0.0164	0.0167	0.0163	0.0152	0.0165	0.0161	0.0163	0.0168
Oct	0.0170	0.0170	0.0167	0.0175	0.0168	0.0153	0.0162	0.0170	0.0168	0.0168
Nov	0.0176	0.0180	0.0176	0.0177	0.0176	0.0176	0.0173	0.0172	0.0170	0.0173
Dec	0.0174	0.0179	0.0177	0.0176	0.0171	0.0166	0.0167	0.0172	0.0168	0.0170
Average	**0.0169**	**0.0169**	**0.0170**	**0.0169**	**0.0167**	**0.0166**	**0.0167**	**0.0167**	**0.0168**	**0.0171**

Appendix E: Monthly Maximum Wind Speed (m/s) from 2011 to 2020.

Month	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	3.2667	3.0435	3.2160	4.1134	3.5032	3.4668	2.7411	2.5867	4.0479	3.6287
Feb	3.1363	2.8345	3.0990	3.6819	3.7751	4.3590	3.4633	3.7850	3.4884	4.2236
Mar	2.7113	2.5107	2.6936	3.3059	2.8048	3.2602	2.6846	2.9623	2.7982	2.8422
Apr	2.4089	2.5284	2.5539	2.2929	2.4749	2.4543	2.5532	3.0344	2.3376	2.7034
May	2.6095	2.6112	2.2975	2.2994	2.3538	2.3764	2.5331	2.2867	2.8625	2.5420
Jun	2.4455	2.6802	3.0060	2.9664	2.5677	2.6541	2.2933	2.6698	2.7199	2.8579
Jul	2.7481	2.8227	2.5895	2.9462	2.9135	2.5889	2.8995	3.1728	2.6669	2.8641
Aug	2.7899	2.5841	2.7728	2.8084	2.8939	2.9732	2.8992	3.2797	3.0469	2.8211
Sep	2.7519	2.6599	2.9539	2.7295	2.8114	2.9627	2.9180	2.6900	2.8757	3.0693
Oct	2.9344	2.6105	2.7719	2.4750	2.8584	3.4778	2.7675	2.6916	2.3645	2.9391
Nov	2.7923	2.4222	2.5325	2.5537	2.5005	2.3738	2.8647	2.7408	3.0323	2.6486
Dec	2.9829	2.6515	3.4024	2.8407	3.0657	3.0401	2.8752	2.8707	3.9863	2.6813
Average	**2.7981**	**2.6633**	**2.8241**	**2.9178**	**2.8769**	**2.9989**	**2.7911**	**2.8975**	**3.0189**	**2.9851**

Appendix F: Monthly Surface Air Temperature (ºC) from 2011 to 2020.

Month	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Jan	23.8726	24.5826	24.7093	23.7324	24.0260	25.7564	24.8986	24.5470	25.0665	25.2951
Feb	24.6926	25.0287	24.6112	24.8938	24.4672	25.1481	24.9222	24.7935	25.4921	25.1863
Mar	25.0051	25.1118	26.0063	25.8066	25.4390	26.5428	25.4353	25.6624	26.2569	26.4014
Apr	25.4770	25.7862	26.1401	25.9752	26.0495	27.2801	25.8426	26.2229	26.9378	26.5027
May	25.8961	25.9546	26.1677	26.5838	26.3976	26.9359	26.2682	26.3595	26.7378	26.6321
Jun	25.6829	26.0980	26.3119	26.7624	25.9985	25.9212	26.0065	25.6578	26.1794	25.7195
Jul	25.3629	25.2682	25.6141	26.3109	25.7411	25.6254	25.5310	25.3717	25.9373	25.4323
Aug	25.3347	25.4282	25.5107	25.5137	25.7499	25.8601	25.3514	25.6138	25.8700	25.8317
Sep	25.3035	25.3352	25.3390	25.7829	25.7037	25.6743	25.4401	25.5142	26.0849	25.3615
Oct	25.0791	25.3984	25.3068	25.6191	25.8943	25.3469	25.7317	25.6050	25.8339	25.4583
Nov	24.8572	25.3752	25.2039	25.2294	25.6527	25.4950	25.2155	25.2998	25.5533	25.3155
Dec	24.5647	24.9592	24.5202	24.6991	25.4353	24.8481	25.1169	25.3693	24.6715	24.9017
Average	**25.0940**	**25.3605**	**25.4534**	**25.5758**	**25.5462**	**25.8695**	**25.4800**	**25.5014**	**25.8851**	**25.6698**

Appendix G: Interpretation of Correlation Coefficient.

Scale of Correlation Coefficient	**Value**	**Scale of Correlation Coefficient**	**Value**
0.00 – -0.199	Very Weak Negative	0.00 – 0.199	Very Weak Positive
-0.20 – -0.399	Weak Negative	0.20 – 0.399	Weak Positive
-0.40 – -0.599	Moderate Negative	0.40 – 0.599	Moderate Positive
-0.60 – -0.799	Strong Negative	0.60 – 0.799	Strong Positive
-0.80 – -1.000	Very Strong Negative	0.80 – 1.000	Very Strong Positive