GIS-BASED SOIL EROSION AND SEDIMENT TRANSPORT MODELLING OF PERAK RIVER BASIN

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by

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ABSTRAK

Kegagalan tebing sungai adalah kejadian biasa di Malaysia, terutama pada musim hujan. Komposisi tekstur tanah di tebing sungai yang ditunjukkan oleh darjah atau tahap hakisan tanah, adalah salah satu perkara penting yang mempengaruhi hakisan tebing sungai. Semua sampel tanah yang diperoleh di sepanjang tebing Lembangan Sungai Perak akan melalui proses ayak dan ujian makmal hidrometer dan skala "ROM" (dinamakan sempena penyelidik ROslan dan Mazidah) digunakan untuk menentukan tahap hakisan tanah boleh berlaku, iaitu tahap rendah, sederhana, tinggi sangat tinggi, dan kritikal di sepanjang tebing sungai, berdasarkan komposisi peratusan pasir, kelodak, dan tanah liat. Potensi kegagalan tebing sungai di sepanjang sungai dapat diperoleh dengan menentukan tahap hakisan tanah. Penggunaan Sistem Maklumat Geografi (GIS) adalah untuk memetakan hakisan tanah. Interpolasi akan dibuat dengan menggunakan GIS untuk meramalkan risiko hakisan di sepanjang Sungai Perak. Pemetaan GIS digunakan untuk gambaran terbaik mengenai risiko hakisan kerana ia menunjukkan risiko lokasi tertentu dalam warna. Hasil daripada maklumat penting ini, pihak berkuasa pemerintah dan swasta yang terlibat dapat merancang, mengembangkan, dan melaksanakan langkah-langkah pencegahan yang paling tepat untuk menghentikan hakisan tebing sungai. Jumlah Pepejal Terampai juga akan dibandingkan dengan komposisi tanah untuk mencari hubungannya. Hasil TSS akan diperoleh dari ahli pasukan untuk dibandingkan dengan tahap risiko hakisan tanah untuk melihat sama ada lokasi yang berpotensi tinggi hakisan tanah berlaku akan mempengaruhi nilai TSS. Kesimpulannya, kajian ini penting untuk melindungi alam sekitar. Walaubagaimanapun, Jumlah Pepejal Terampai bukanlah kajian utama untuk projek penyelidikan ini.

ABSTRACT

Riverbank failures are a typical occurrence in Malaysia, particularly during the wet season. The textural composition of riverbanks, which may be represented by the degree or level of soil erodibility, is one of the important variables influencing riverbank erosion. All soil samples collected along the riverbank of the Perak River Basin were sieved and hydrometer tested, and the “ROM” Scale (named after the researchers ROslan and Mazidah) was used to determine the degree of soil erodibility, namely low, moderate, high, very high, and critical along the riverbank, based on the percentage composition of sand, silt, and clay. The potential of riverbank failure at every point along the river may be obtained by determined the soil erodibility level. The use of the Geographical Information System (GIS) is for mapping soil erosion. Interpolation will be made by using GIS to predict the risk of erosion along the Sungai Perak. GIS mapping is used for the best illustration of erosion risk as it presents the risk of a certain location in colours instead of in number. As a result of this vital information, the involved government and private authorities will be able to plan, develop, and implement the most appropriate preventative measures to stop riverbank erosion. Total Suspended Solid (TSS) value will also be compared with the soil composition to seek its relation. TSS result will be obtained from team members to be compared with soil erosion risk level to see whether the location that have high potential risk of soil erosion will effect TSS value. In conclusion, this study is important to protect the environment. However, TSS is not the major study for this research project.

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A	Final weight of filter + Dried residue, mg
B	Weight of filter, mg
%	Percentage

LIST OF ABBREVIATIONS

BESI	Bank Erosion Susceptibility Index
CCs	Cover Crops
EI_{ROM}	Erodibility Index
GIS	Geographical Information System
NWQS	National Water Quality Standard for Malaysia
"ROM"	ROslan and Mazidah
SMG	Sistem Maklumat Geografi
SWC	Soil and Water Conservation
TSS	Total Suspended Solid
USM	Universiti Sains Malaysia

CHAPTER 1

INTRODUCTION

1.1 Overview

Rivers are highly important to human society. It has a diverse range of uses and major areas for human occupation and habitation. Rivers are used for a variety of things, including drinking and municipal water, industrial and cooling water, power generation, navigation, commercial and recreational fisheries, body contact leisure, boating, and other aesthetic recreational activities. Furthermore, it is widely assumed those vast rivers have an unlimited capacity to consume or dilute industrial and urban waste (Arriafdi et al., 2016).

However, urbanisation and land growth have resulted in several issues, including riverbank flooding, riverbed destruction, encroachment on river buffer zones, and loss of river water quality. River sand extraction, sand and gravel mining, and the use of aggregates in the construction of roads and buildings are only a few of the operations. In Malaysia, stream mining is the primary source of sand. A stream channel's natural equilibrium can be disrupted by excessive sand removal. It will affect sediment flow through the river system, affecting sediment mass balance downstream and triggering channel changes that will stretch well beyond the extracted site (Teo et al., 2017).

Malaysia is also known for being a major producer of oil palm, which has made a significant contribution to the agricultural industry in the region. In 2017, Malaysia ranked second in the world in terms of oil palm exports, with a total value of USD 9.7 billion (Tang and Al Qahtani, 2020). The rapid expansion of oil palm plantations will result in soil loss of up to 4 tonnes per hectare per year. Water contamination in local rivers has been exacerbated by soil erosion in oil palm plantations. During land preparation, such as forest clearing or replanting, the production of oil palm plantations can cause the highest rate of soil erosion and sedimentation. This condition would be exacerbated by Malaysia's climate, which is characterised by heavy rainfall (Sahat et al., 2016).

Malaysia has an equatorial climate, which means it is hot and humid. The northeast and southwest monsoons effect the climate. Between November and February, the former brings heavy rainfall, up to 600 mm in 24 hours in severe cases (Ramizu and Halim, 2015).

Soil erosion is generally determined by three processes: soil loosening, transportation, and deposition (Issaka and Ashraf, 2017). These processes typically result in the topsoil, which is rich in organics, nutrients, and soil life, being transferred elsewhere on-site, where it accumulates over time, or is transported off-site, where it collects in drainage channels. It is typically serious in sloppy, unprotected areas (Issaka and Ashraf, 2017; Shi et al., 2012). Soil erosion has a negative effect on plant growth, agricultural yields, water quality, and recreation. Since it occurs naturally on all soils, it is a significant cause of soil depletion (Issaka and Ashraf, 2017; Posthumus et al., 2015; Ding et al., 2015; Bai et al., 2010).

The erosion process can occur at a slow rate, where it typically goes unnoticed, or it can occur at a high rate, resulting in a substantial loss of the upper part of the soil. On cropland, soil erosion causes a reduction in yield capacity, a decrease in surface water quality, and a breakdown in drainage systems (Issaka and Ashraf, 2017; Montgomery et al., 2014; Munodawafa, 2012; Rahman et al., 2009). Soil erosion is most common in areas where the topography is sloped and where long periods of rainfall coincide with a lack of vegetative cover (Issaka and Ashraf, 2017; Zhao et al., 2014; Rohrmann et al., 2013; Vrieling et al., 2009; Marques et al., 2007; Lee and Lee, 2006).

Bad land management, which damages the soil and induces water runoff through the landscape instead of sufficient infiltration, is one of the factors that causes soil erosion (Issaka and Ashraf, 2017; Liu, 2016; Niu et al., 2015; Montgomery et al., 2014; Nadeu et al., 2012). Soil erosion can be caused by contamination of water sources and loss of cropland. Rainwater is one of the primary causes of soil erosion. It breaks up the dirt, dislodging it from its surroundings, and washing it away as runoff. The form of land use has an effect on soil erosion as well (Issaka and Ashraf, 2017; Liu, 2016; Sun et al., 2014). Soil erosion not only depletes soil nutrients and degrades properties, but it also causes a slew of off-site environmental issues including flooding, siltation, and pollution (Issaka and Ashraf, 2017; Al-Wadaey and Ziadat, 2014; Gao et al., 2012; Dahal et al., 2011; Ouyang et al., 2010; Yu, 2008).

Sedimentation is the final step in the soil erosion and sedimentation cycle. Since sediment yield is dependent on soil erosion, sedimentation is a critical parameter to consider when determining the reservoir's existence. Sedimentation is the process by which sediment particles separate from their source and become deposited as bed load and suspended load.

The erosive effect of rainfall and runoff, according to Dutta (2016), breaks away sediment particles from the catchment of the reservoir due to extreme shear stress produced by the interaction of kinetic energy of raindrops and soil surface. Suspended sediments bear nutrient and contaminant loads that can damage aquatic environments (Bilotta and Brazier, 2008; Wood and Armitage,1999) as well as the water's suitability for human consumption. Nonpoint nitrogen pollutants, heavy metals, and chemicals are also transported with soil particles, resulting in higher sediment levels and, consequently, water eutrophication and destruction of fragile aquatic habitats (Issaka and Ashraf, 2017; Bing et al., 2013; Wilson et al., 2008).

As a consequence, sediment yield and soil erosion are significant variables that can be used to regulate water quality (Issaka and Ashraf, 2017). According to Roslan (2017), soil composition can cause soil erosion because soil particles with strong interlocking can withstand rain. Past researchers devised the "ROM" scale (named after the researchers, Roslan and Mazidah) to determine the degree of soil erodibility, for example low, moderate, high, very high and critical in order to determine the potential risk of soil erosion for a given area.

Sieve analysis and hydrometer test will be used to assess the percentage of clay, sand, and silt in order to determine the risk level. As soil loss can increase the concentration of suspended solids in the river, the risk level will be compared with the total suspended solid (TSS) value. Furthermore, higher TSS concentrations can endanger aquatic life by reducing the production of oxygen (Shah et al., 2014). The use of a Geographical Information System (GIS) to create a map of risk levels for all locations is an excellent approach to deliver spatial information more apparent. Furthermore, GIS provides effective tools for storing and analysing large amounts of spatial data (Islam et al., 2017).

1.2 Problem Statement

Since many areas in Perak are undergoing rapid growth, including land clearing for house building, logging operations, and the opening of new agricultural areas, Malaysia as a whole is experiencing soil erosion (Omar et al., 2018). Direct sand extraction from rivers has been a traditional source of sand, according to Saleh et al. (2017), and it is well recognised that it has a major effect on river morphology.

Excessive sand removal can disturb the natural equilibrium of a stream channel, disrupting sediment flow through the river system, disrupting sediment mass balance downstream, and causing channel changes that reach well beyond the extracted site. River bank erosion, river bed depletion, river buffer zone encroachment, and loss of river water quality are all consequences of in-stream sand mining (Teo et al., 2017).

Furthermore, prolonged rain caused soil erosion, which resulted in debris being transported into the river (Rahmani et al., 2018). As a result, in order to find a solution to the issue, this study is being carried out to investigate the physical soil properties and soil erodibility on soil erosion within the lower basin of the Perak River. For better illustration, a mapping tool is required.

1.3 Objectives

The objective of this study are as follow:

1) To investigate the soil physical properties of soil erosion which are type of soil and particle size.
2) To determine the soil erodibility within the downstream of the Sungai Perak.
3) To develop a soil erosion map using GIS to illustrate the level of soil erosion risk.

1.4 Scope of Work

To gain knowledge by using 66 publications, papers, and various books for the literature study.

Sieve analysis and the hydrometer test are the two laboratory tests that must be performed. The purpose of this test is to determine the percentage of the grain size of the soil in the study area.

The outcome would be used in the "ROM" scale model to assess the risk level of soil erosion at downstream of Sungai Perak.

The result of the “ROM” scale will be compared with TSS value from team members to determine the relationship between soil erosion risk location with TSS value.

1.5 Dissertation Outline

The dissertation for this project has been divided into five chapters.

Chapter One serves as an overview. This section contains information about the study's history, intent, and concentration, as well as the dissertation's context. This assists the reader in comprehending the study's intent as well as the research's overall scope.

Chapter Two is the literature review, that explains the analysis that was undertaken to learn more about the topic of the report. The literature review in this case, consists of a detailed understanding of soil erosion, as well as the origin and current state of the Perak River.

Chapter Three describe the methodology to conduct this research project. The protocol for the laboratory test and the "ROM" scale model are described in detail in this chapter in order to obtain the results. GIS would be used to plot out the outcome.

Chapter Four, the physical properties of the soil will be discussed as well as the results obtained from the "ROM" scale model. To investigate the relationship between soil risk and TSS, the outcome is compared to the TSS value.

Chapter Five, there will be a discussion of the findings and possible conclusions. Based on the results, recommendations can be made, and changes can be prepared for future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter summarizes the literature review that has been done for the study. Information about soil erosion detailly to support this research study. Understand this phenomenon and several factors that influence it to happen. Next, this chapter also represents the method that will help to solve the problem for preparation in future.

2.2 Soil Erosion

Soil degradation is a big environmental issue. It may result in issues such as degradation of the physical, chemical, and biological properties of the soil. (Li et al., 2016; Lal et al., 2000). Soil erosion may happen spontaneously or be hastened by human action. Natural soil depletion typically happens at a rate that is nearly equal to the rate of geologic soil formation. (Haruna et al., 2020).

Soil erosion causes both on-site and off-site consequences that are harmful to both plants and animals. Inter-on-site and off-site effects could compound the effects. Inter and intra-ecosystem responses, as well as flora and fauna, could increase the consequences (Issaka and Ashraf, 2017).

Soil erosion is generally determined by three processes: soil loosening, transportation, and deposition. The top layer, which is rich in organics, minerals, and soil life, is typically transferred as a result of these methods. It either accumulates on-site over time or is shipped off-site and accumulates in irrigation channels. It is normally serious in sloppy, unprotected environments. Soil erosion processes affect how much water a soil can bear, how quickly water runs over it, and how it moves under the surface (Issaka and Ashraf, 2017).

The topsoil, which is rich in organics, nutrients, and soil life, is frequently relocated elsewhere on-site where it builds up over time or transferred off-site where it collects in drainage channels as a result of these processes. It is frequently severe in sloppy, vulnerable regions (Shi et al., 2012). The erosion process is linked to pollution of local water bodies and wetlands, as well as a decrease in farmland production. Soil erosion has a negative impact on plant development, agricultural productivity, water quality, and recreation. Since it occurs naturally in all areas, it is a major driver of soil degradation (Bai et al., 2010).

Water and wind are the main sources of soil erosion, with both contributing to a large amount of yearly soil loss. On cropland, soil erosion causes a reduction in yield potential, a decrease in surface water quality, and a breakdown in drainage systems (Munodawafa, 2012). The erosion phenomena can occur at a moderate rate, where it normally goes unnoticed, or it can occur at a fast rate, resulting in a significant loss of the upper section of the soil. Sediment yield and soil erosion are important elements that can be used to control water quality.

Soil erosion is a process that causes irreversible on-site soil deterioration and is assessed by the average amount of soil taken from an area over a set time. The sediment yield is the amount of soil that is separated and transported to surface water bodies during a time scale across a certain area, and it is a key procedure in catchment erosion (Issaka and Ashraf, 2017).

Mass movement is the collective material movement of soil and/or rock downslope under the action of gravity, without necessarily being impacted by water or ice. Water or ice, on the other hand, can reduce the shear strength of slopes, causing soils to behave like plastics or, in very wet conditions, as fluids. As a result, the mass movement could become much more disastrous, resulting in even more destruction and deaths (Guerra et al., 2017). Although both soil erosion and mass movement are form of land degradation in which humans play an essential role, they have various modes of occurrence and, as a result, different ways of being identified and monitored, as well as different characteristics. Ultimately, the best method to avoid both types of land degradation is to take preventative measures, which entails understanding the dangers of soil erosion and/or mass movement and taking steps to mitigate them (Guerra et al., 2017). Preservationists strive to keep landscapes and ecosystems as unaffected by humans as possible.

2.2.1 Riverbank Erosion

Hundreds of millions of people throughout the world rely on rivers for survival. The sediment transfer along the river segment has an impact on the river's water quality, storage capacity, and navigation. The majority of these tonnes of silt arise from river bank collapsibility, especially during the cycle of the flood-scarcity season (Aldefae et al., 2020). Riverbank erosion is a serious and unpredictably dangerous hazard especially in Malaysia. The prone ground that makes an angle with the horizontal plane is known as a slope. At river banks, soil detachment is caused by two processes: 1) hydraulic erosion caused by channel flow, and 2) sub aerial erosion caused by the deterioration and weathering of bank components (Abidin et al., 2017).

Slope collapse will occur on slopes that are not monitored. The failure of a river's slope is usually linked to many causes that might degrade the area's soil structure and result in the deposition of soil sediments. Erosion, on the other hand, is the process of cutting or sliding surface slopes and the transfer of materials by erosion agents such as moving air, wind, and precipitation (Ngadiman et al., 2021).

There are three types of river-bank erosion which are rill erosion, sheet erosion and gully erosion. Rill erosion is a moderate kind of erosion that falls between sheet and gully erosion. Rills are shallow waterways that are generally less than 30 cm deep and can be many metres long (Ngadiman et al., 2021). In many parts of the globe, rill erosion is one of the processes of soil loss by water on sloping croplands and rangelands. Rill erosion is influenced by two key factors: rainfall intensity and slope gradient. Rill erosion frequently increased as rainfall intensity and slope gradient rose (Shen et al., 2016).

Gully erosion is incised channels, which often began as rills. Gullies are highly effective conveyors of sediment to rivers and their density and depth are indicators of the severity of erosion (Harden, 2016). The most prevalent and least harmful type of erosion is sheet erosion. During heavy rains, it happens swiftly, although it's readily halted by vegetation. Surface water runoff will erode and move details of land that have been impacted by rainfall splashes. As a result, little swaths of dirt on the slope's surface disintegrate. After the top layer of soil is lost, a visible layer of dirt is exposed on the surface, which is a major consequence of sheet erosion. In such layers, replanting vegetation is extremely difficult (Ngadiman et al., 2021).

The shearing away of bank material or the liquefaction and flowage of bank lines can both be blamed for the declination of bank lines in large river systems. This type of erosion happens during both flood and low flow seasons (Tripathy and Mondal, 2020). The river gets shallow as a result of erosion. This is due to hydraulic action, which occurs when water pressure breaks down rock particles at the riverbed's and banks' bottoms. Furthermore, the air is compressed, the pressure rises, and the riverbank is at risk of collapsing. Through the attrition process, the eroded rocks collide and split into smaller bits. Deposition occurs when the sediments get smaller and more rounded as they go downstream (Ngadiman et al., 2021). Either natural or man-made processes can undermine the bank. However, the most significant impacts are often seen in the basin's people's economies, with villages being destroyed or cultivated land being damaged.

2.2.2 Factors affecting soil erosion

Wind and water have been identified as two main agents of erosion in previous studies. In certain parts of the world, water is regarded as the most natural cause of soil erosion. The erosion of river basins, landforms, and seashores are all examples of water's effect as an agent. Water erodes soil and moves soil particles from higher altitudes to lower elevations, where they are deposited. In contrast to wind, water has been reported as a significant cause of soil erosion problems (Abidin et al., 2017). Wind can also degrade soil quality and facilitate erosion, especially when the soil structure is loose. Winds that are less strong are less likely to inflict harm. Sandy or lighter soils that are readily carried through the air are the most vulnerable soils to this form of erosion (Sholagberu et al., 2016).

Furthermore, one of the causes is climate change. Both soil erosion and mass movement mechanisms are affected by climate regimes. When it comes to rainfall, most erosion occurs over time during occurrences of intermediate frequency and severity, while catastrophic storms are not often enough to generate significant net erosion. This is a short-term perspective: soil loss is substantially higher during high-magnitude events than during moderate rainfalls; big precipitation events are the primary cause of gully incision in many environments (Guerra et al., 2017). Climate change would impact plant biomass production, infiltration rate, soil moisture, land usage, and field