SEDIMENT TRANSPORT STUDY AT PENDIAT, SUNGAI PERAK

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SEDIMENT TRANSPORT STUDY AT PENDIAT, SUNGAI PERAK

By

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I hereby declare that all corrections and comments made by the supervisor(s)and examiner have been taken into consideration and rectified accordingly.

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I never imagined having the opportunity to write this section. I believed the moment to write this section would never come. Now is the moment to conclude and offer my appreciation to everyone who has supported me to complete this project. Without assistance from individuals, this project would never be completed. Therefore, I am using this moment to list a few of them; please pardon me if I forgot your name. I hope you believe that despite this oversight, I appreciate and respect you all.

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KAJIAN PENGANGKUTAN SEDIMEN DI PENDIAT, SUNGAI PERAK.

ABSTRAK

Di Perak, Malaysia, sistem sungai dengan dasar pasir telah dilombong untuk pasir sungai selama beberapa dekad. Disebabkan kekurangan pengurusan yang lestari, aktiviti ini telah mengakibatkan pelbagai kesukaran, seperti hakisan tebing sungai, hakisan dasar sungai, pemendapan, dan penurunan kualiti air sungai. Penyingkiran pasir yang berlebihan berpotensi untuk mengubah keseimbangan semula jadi sistem sungai dengan ketara. sehubungan dengan itu,usaha penyelidikan mengenai perlombongan pasir sungai untuk membangunkan cadangan bagi pengurusan jangka panjang operasi perlombongan pasir perlu dipertingkatkan. Aliran sedimen dalam saluran terbuka adalah proses fizikal yang sukar yang belum disiasat sepenuhnya. Ia mempengaruhi bentuk sungai, yang sentiasa berubah disebabkan oleh mekanisme penghantaran sedimennya. Dengan menggunakan perisian Sistem Analisis Sungai Pusat Kejuruteraan Hidrologi (HEC-RAS), profil sungai sedimen satu dimensi telah dihasilkan. Terdapat tujuh keratan rentas (L1-L7) sepanjang 3.16 km sungai yang telah disimulasikan dari 5 Oktober hingga 24 Oktober 2021. Simulasi dijalankan dengan memasukkan data geometri sungai, data aliran dan data sedimen. Di samping itu, persamaan Yang telah digunakan dalam simulasi HEC-RAS. Profil sungai mendedahkan pemendapan dan hakisan dasar sungai. Daripada simulasi, hanya baris 5 menunjukkan proses pemendapan manakala enam baris lagi menunjukkan proses hakisan. Analisis pemodelan sedimen telah menemui implikasi persekitaran fizikal yang ketara. Perbincangan mengenai penemuan dan beberapa penyelesaian untuk pengurusan sedimen untuk mengelakkan proses kemerosotan dan keterukan telah dibentangkan.

SEDIMENT TRANSPORT STUDY AT PENDIAT, SUNGAI PERAK.

ABSTRACT

In Perak, Malaysia, river systems with sand beds have been mined for decades. Due to a lack of sustainable management, these activities have resulted in a variety of difficulties, such as riverbank erosion, riverbed degradation, sedimentation, and a decline in river water quality. Excessive sand removal has the potential to substantially alter the natural balance of a river system. Consequently, it is crucial to do more research on river sand mining to develop suggestions for the long-term management of sand mining operations. Sediment flow in open channels is a physically difficult process that has not been fully investigated. It influences the shape of the river, which is continually changing due to its sediment delivery mechanism. Utilizing the Hydrologic Engineering Centers River Analysis System (HEC-RAS) software, a one-dimensional sediment river profile was generated. There were seven cross-sections (L1-L7) along the 3.16 km of the river had been simulated from 5 October to 24 October 2021. The simulation was conducted by entering the river geometry data, flow data, and sediment data. In addition, the Yang equation was utilised in the HEC-RAS simulation. The river profile revealed the deposition and erosion of the riverbed. From the simulation, only Line 5 shows the deposition process, while another six lines show the erosion process. Analyses of sediment modelling have found significant physical environmental implications. A discussion of the findings and some solutions for sediment management to prevent the deterioration and aggradation processes were presented.

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LIST OF ABBREVIATIONS

1D	One dimensional
ADCP	Acoustic Doppler Current Profiler
DID	Department of Drainage and Irrigation Malaysia
UNESCO	United National Educational, Scientific and Cultural Organization
HEC-RAS	Hydrologic Engineering Centres River Analysis System
ASCE	American Society of Civil Engineers
ASL	Above sea level

LIST OF SYMBOLS

C_{pt}	Sediment concentration (in ppm by weight)
Re*	Shear Reynolds number = $\frac{w_s d_{50}}{v}$
w_s	Fall velocity of sediment
d_{50}	Mean diameter of sediment
N	Manning number
U*	Shear velocity
S_0	Slope of river profile
V_c	Unit stream power
V_cS	Critical unit stream power required at incipient motion
v	Kinematic viscosity
q_s	Sediment transport rate by weight per unit width
Γ	Specific weights of water
γ_s	Specific weights of sediment
V	Average velocity of river profile
G	Acceleration due to gravity
τ_0	Shear stress
R	Hydraulic radius
Y	Depth of river profile
Q_s	Calculated sediment load
Q_j	Replenishment rate
R^2	Coefficient of determination
M	Meter
m/s	Meter per second

m^3/s	Meter cubic per second
km^2	Kilometre square
kg	Kilogram
kg/m^2	Kilogram per meter square
kN/m^3	Kilonewton per meter cubic
Hz	Hertz

CHAPTER ONE

INTRODUCTION

1.1 Background

The river is a living system. Hydraulic and sediment transport mechanisms govern it. Gradually, the river undergoes changes in channel cross-section, erosion and deposition along the channel, and increased or decreased sediment carrying capacity, all which impact bank stability and ultimately result in morphological modifications. Rapid growth in river catchment regions will increase surface runoff and lead to an increase in sediment delivery. All these factors will not only change the shape of the river but also induce channel instability. Consequently, it will cause severe damage to hydraulic infrastructure along the river, such as dams and spillways, sluice gates, weirs, and flumes. For river restoration, it is essential to examine the river channel's stability. The estimation of sediment transport rate is essential for the fundamental design of hydraulic structures, the management of scour issues, and the construction and maintenance of channels.

In recent years, the need for sand in the building industry has increased, particularly in rapidly developing urban areas. Riverbeds are the principal sand supply. Rapid urbanisation has raised the need for river sand as a building resource. Illegal and inefficient sand mining is a significant consequence of the rising demand for sand. The widespread use of sand for construction has led to the deterioration of rivers. In addition, the inappropriate sand mining operation has caused riverbank and riverbed damage. So, without a clear set of laws, sand mining has happened without control or oversight, which has made environmental problems worse (Najib et al., 2019).

This research focuses on sediment movement and sediment deposition along the Sungai Perak at Pendiat because of sand mining operations. In addition, the effects of excessive sand mining along the Sungai Perak at Pendiat will be investigated. Riverbank erosion and scouring is one of the effects. Using HEC-RAS software, the riverbed of the Sungai Perak near Pendiat will be modelled.

1.2 Study Area

The study was carried out at a river located in Sungai Perak, a natural stream in Perak, Malaysia, around the Pendiat area. Sungai Perak has a catchment area of 14,908 km^2, but this study is focusing only on the Kg. Pendiat area. The study area is limited to 3.16 kilometres of Sungai Perak at Kg. Pendiat. Sungai Perak is the second-longest river in Peninsular Malaysia. It is one of the sources of water supply for the local community. It is also used for recreation, fishing, mining, and watering farms.

This study analyses and evaluates sediment transport using flow measurements from an Acoustic Doppler Current Profiler with seven cross-sections of data. This study would show how the movement of sediment changes the depth of the riverbed, which is a problem in Sungai Perak because it affects the stability of the riverbanks and riverbed.

Figure 1.1 shows the study area along the length of the river at Kg Pendiat with the coordinates of the right and left bank. The length of the river is measured from the centre of the line. The cross-sections started at Line 1 and Line 7. Line 7 is upstream of the river, while line 1 is the last cross-section taken at Kg, Pendiat, which is downstream of the river. The overall length of the river taken is around 3.16 kilometres.

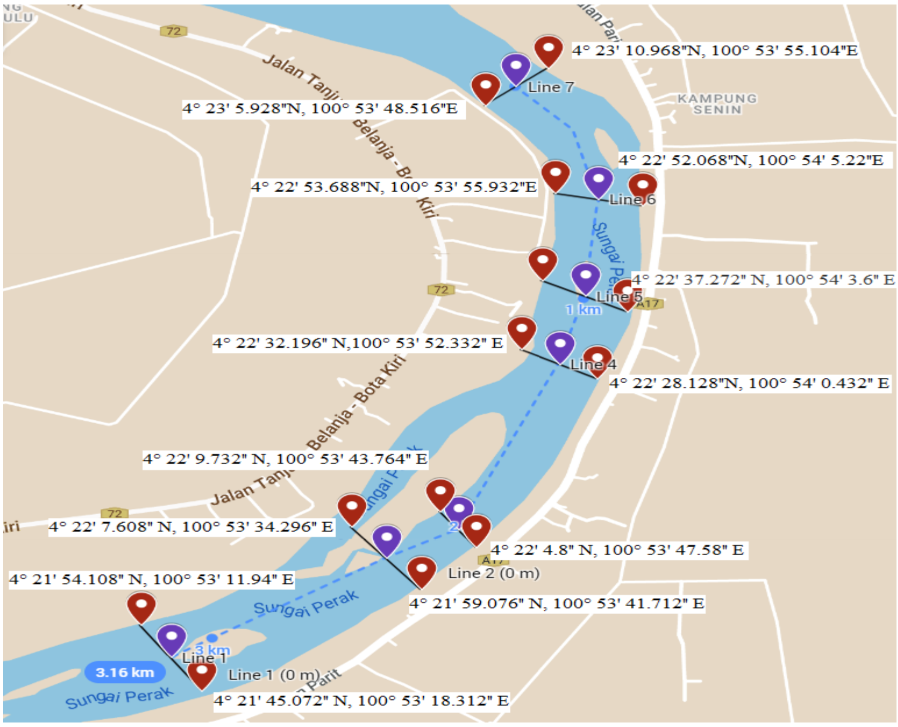

Figure 1.1: Area of study in Sungai Perak at Pendiat, Perak

(Google Maps, 2022)

1.3 Problem Statement

In recent years, due to the rapid development, sand mining activities have created several issues that need urgent attention in Malaysia's rivers. Presently, there are 13 sand mining companies along the Sungai Perak in Perak Tengah District. Some small companies in Malaysia are lacking in technologies and have poor management of sand mining, which can significantly lead to the unreliability of controlling the sand mining activities. It can cause problems if the sand extraction is interrupted. It has caused the deterioration of river water quality, bank erosion, riverbed degradation, etc. All those problems were mainly caused, possibly, by the excessive sand extraction along the river stretches.

One of the effects of improper management of sand mining is erosion of the riverbank. The eroded sediment is transported and the deposited sediment will decrease the river depth, which increases the difficulties in supplying water for irrigation and local communities' usage. Therefore, high costs are needed for water quality assessment and control. Moreover, sediment deposition is a culprit in the slow reduction of aquatic habitats and increased water velocity, which changes the morphology of rivers (Aziz et al., 2021). If a body of water is constantly exposed to a lot of sediment transport, sensitive species may move away, leaving the area dominated by species that can handle the silt.

Mining for sand in a stream might create instability. The instability of the river channel is a result of the riverbed's lateral (horizontal) and vertical (vertical) alterations (Amangabara et al., 2008). Using HEC-RAS, the change in the riverbed is simulated. Furthermore, direct sand mining from rivers has been a frequent supply of sand despite the well-known negative effects on river morphology (Ladson & Judd, 2014). Hence, it is crucial to study the assessment of the sediment transport simulations of the Kg. Pendiat river. It is because river sediment transport simulation is a critical aspect of river environment conservation.

1.4 Objectives

The objectives of this study are as follows:

a) To simulate sediment transport modelling of Sungai Perak at Pendiat using HEC-RAS.
b) To identify the erosion and deposition riverbed at the study cross sections of Pendiat, Sungai Perak.

1.5 Scope of Work and Limitations

The study scope of work is limited to a preliminary study of the hydrology of the surrounding area. The scope of work is limited to:-

i. 3.16 kilometres of Sungai Perak at Pendiat with seven cross-sections of data.
ii. Limited to the data collected and obtained in the September and October of 2021
iii. The sediment transport equations used for the study in HEC-RAS simulation is Yang equation.

1.6 Importance of Study

By understanding the simulation and analysing the simulation of the Sungai Perak at Pendiat, a suitable measurement can be taken to reduce the scouring of the riverbank and riverbed. Thus, it can ensure the sustainability of the sand by reducing erosion. Besides, the study helps to double check on the erosion and deposition locations, thus helping in choosing a suitable location for sand mining.

1.7 Dissertation Outline

The research project is organized into five chapters, which are as follows:

Chapter 1: The first chapter provides a broad introduction as well as a preview of the research layout. This includes the background, study area, problem statement, objectives, the scope of work and limitations, importance of the study, and dissertation outline.

Chapter 2: Chapter two is the literature review that covers the following areas which are an introduction, positive and negative impacts of sand mining, sediment transport, modes of sediment transport, and sediment transport equations.

Chapter 3: Chapter three outlines the approach, which includes the fieldwork for collecting data as well as the process to obtain the output result.

Chapter 4: Chapter four shows the result of the sediment transport simulation of seven sampling lines. The best fit sediment transport equations will be discussed.

Chapter 5: Chapter five is providing the conclusion and recommendations of the researcher.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

In recent years, sand has had higher demand in the construction industry, especially in urban areas that are undergoing rapid development. The main activity to extract these sources is that of sand mining (Najib et al., 2019). This has resulted in a mushrooming of river sand mining activities, which has given rise to various problems that require urgent action by the authorities (Ikhsan et al., 2021). Rapid and inefficient sand mining could have a negative influence on the ecology and ecosystem. Environmental problems occur when the rate of extraction of sand, gravel, and other materials exceeds the rate at which natural processes generate these materials. Excessive removal of sand may significantly distort the natural equilibrium of a stream channel (Yenn Teo et al., 2017). Besides, excessive sand extraction and illegal sand mining can cause increased turbidity in water and severe riverbank erosion downstream of the river.

Sediment transport is the movement of solid particles of organic or inorganic by water (UNESCO, 2021). Sand mining is one of the disturbances that can influence the characteristics of turbulence in the flow that causes the sediment to start moving. The modes of transport of the sediment depend on the sizes of particles, whether it is wash load, bedload, or suspended load (Ashraf et al., 2011). By predicting the river sediment load, the removal capacity of sediment can be determined to reduce the risk of a flood (Saleh et al., 2017).

2.2 Site Introduction

The study focuses on Sungai Perak at Kg. Pendiat, Bota, Perak area. Sungai Perak is Peninsular Malaysia's second longest river, flowing from the Titiwangsa and Bintang mountain ranges upstream, with a catchment area of 14,908 km^2. Sungai Perak not only serves as a source of water for the community, but it is also used for recreational purposes, fishing, mining, irrigation of agricultural areas, and a variety of other human activities. In December 2014, Sungai Perak was hit by heavy flooding (Berita Harian Online, 2014). It was reported that the worst flood in the history of the study area occurred in late 2014 and early 2015. In this study, seven river cross sections were chosen at Kg. Pendiat Sungai Perak. The study area in Sungai Perak, Perak, is visualised in Figure 2.1.

Figure 2.1: The locations of study area in Sungai Perak at Pendiat, Perak. (Google Earth, 2022)

2.3 Sand Mining Positive Impacts

Sand mining has in some way impacted the economic, social, and environmental aspects of human life in mining areas (Mngeni et al., 2016). Despite the common perception that sand mining has negative impacts, river sand mining can provide benefits. It benefits individuals and society by creating employment opportunities. Consequently, sand mining indirectly contributes to the local and regional economies since it creates profit for both individuals and corporations, which has led to a growth in sand mining in the Sadang River in Pinrang Regency. Despite the common perception that sand mining has negative impacts, river sand mining can provide benefits. It benefits individuals and society by creating employment opportunities. Consequently, sand mining indirectly contributes to the local and regional economies since it creates profit for both individuals and corporations, which has led to a growth in sand mining in the Sadang River in Pinrang Regency (Rukmana *et al.,* 2020). According to Ashraf et al., (2011), sand mining is vital to the economy of several nations.

Sand and gravel are abundant in rivers; thus, sand mining is required to provide construction sand. There are several applications for sand and gravel, but the great majority of identified uses involve engineering materials such as cement (Koehnken, 2018). Currently, sand is still used significantly in the building construction industry, but this natural resource is also utilised by a broad number of other industries. Consequently, sand is a fundamental component in several construction materials, including cement, mortar, tile, brick, glass, adhesives, ceramics, etc. Sand also plays an important role in water filtering, chemical and metal processing, and the plastics industry (Dan Gavriletea, 2017).

Since sand mining has an impact on sediment transport. Observations suggest that the locations of mining activities along the channel are areas of natural slope where sand is naturally accumulated (Agubom and Okeke, 2022). Thus, the further sediment is moved, the more abrasion the grains have endured and the more they have been degraded. Due to the correlation between the flow velocity and sediment carrying capacity of the stream, a drop in gradient is frequently followed by a fall in grain size and an increase in grain sorting (Rentier & Cammeraat, 2022). As a result, more sand deposition downstream may be an ideal location for sand mining.

In conclusion, there are still some benefits associated with the mining of sand. Instead of examining the potential benefits of sand mining, this research will concentrate on the drawbacks associated with sand mining. This is due to the fact that excessive sand mining has a detrimental effect on the sediment transport in the river.

2.4 Sand Mining Negative Impacts

According to DID (2010), sand mining can cause harm to both private and public property, as well as aquatic environments. The removal of sand without management may alter the natural balance of a stream channel. River mines disrupt the continuity of sediment transport through the river system by removing sediment from the active channel bed, disrupting the sediment mass balance downstream, and causing channel alterations (typically incision) that extend significant distances (typically 1 km or more) beyond the extraction site itself. Several river degradations, such as flooding, have occurred because of sand mining-induced channel incision. Deeper incision causes bank instability and erosion, leading to channel expansion (Martín-Vide et al., 2010). Instability may also be caused by intensive land use changes, such as agriculture and urbanisation (Rufin-Soler et al., 2008).

Extraction techniques such as pit excavation and bar skimming, which result in riverbed erosion, create channel incision. Thus, the process is also known as head cutting or hungry water. On an active channel, head cutting extraction lowers the stream bed to generate a nick point, which enhances flow energy by steepening the channel slope (Ashraf et al., 2011). Regarding a considerable association between Manning coefficient (n) and sediment grain size (d), instream sand mining disrupts bed roughness caused by tractive force triggered by the deposition of finer sands at the boundary surface of the water flow (Bhattacharya et al., 2019).

Mining usually targets sediment from bedforms (sand deposits) on the riverbed. The loss of sand altered the shape of riverbed, decreased flow velocities, and increased flow turbulence in the vicinity of the mining pits. Bedload transfer is caused by the turbulent character of river and canal flows (Barman et al., 2019). Importantly, a rise in the number of sediment extractions can influence morphological changes that must be monitored (Rukmana *et al.*, 2020). Discharge and sediment are the two primary variables that have a significant impact on the morphological process. When sediment movement happens, it will result in degradation and aggradation along the river, which will alter the morphology of the river (Mananoma & Koagouw, 2019).

Figure 2.2 depicts the sand-and-gravel stream bed, illustrating (A) the nick point that arises because of a pit excavation. A nick point is a sharp shift in stream profile gradient produced by a change in erosion rate. In addition, (B) illustrates the upstream head cutting and downstream bed deterioration that occur during high flow conditions.

Head cutting mobilises huge amounts of streambed sediments, which are then transported downstream and deposited in the excavated region and adjacent areas.

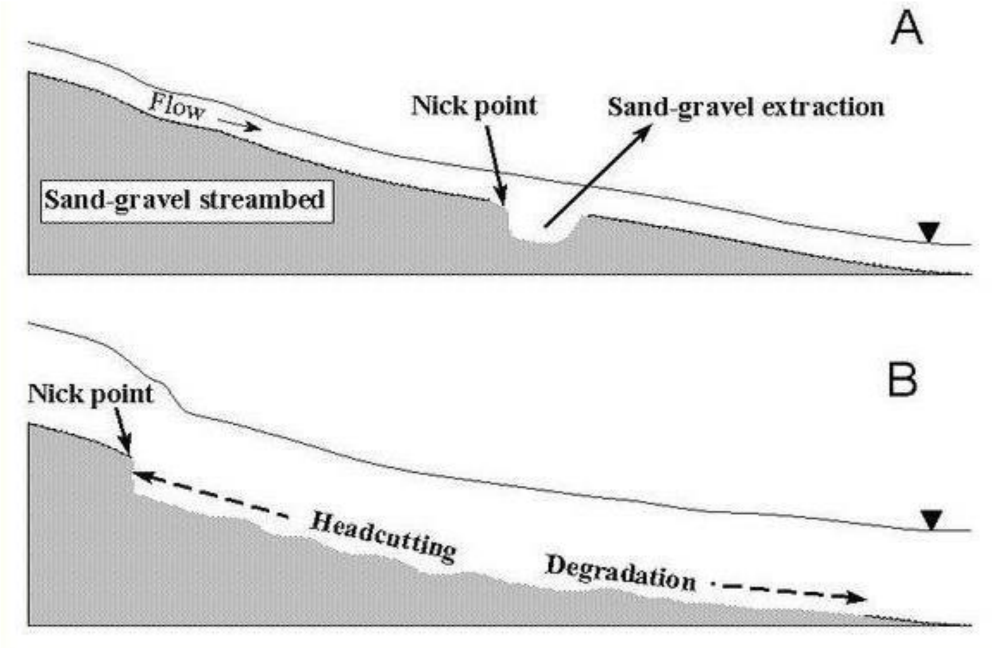

Figure 2.2: The formation of nick point of sand and gravel stream bed, as well as upstream head cutting and downstream bed degradation.

In a study by Bayram & Önsoy (2015) of the Harsit River in the Eastern Black Sea basin of Turkey. the effects of gravel mining on the water quality of river included an increase in temperature, turbidity, manganese, chromium, and iron concentrations related to material extraction and washing, with the increase in metal concentrations correlating with suspended solids. The extraction of sand degrades the quality of water, requiring further treatment for consumers downstream. Increased short-term turbidity at the mining site because of sediment resuspension, sedimentation because of the stockpiling and dumping of excess mining materials and organic particulate matter, and oil spills or leaks from excavation machinery and transportation vehicles are some of the effects (AbdulAzeez, 2016). The eroded particle is referred to as a rise in suspended solids in the water, which impacts aquatic ecosystems. The suspended material might interfere with the household water supply. High water turbidity can raise the cost of drinking water treatment (Ashraf et al., 2011).

2.5 Sediment Transport

Sediment transport systems in rivers continue to be a challenge, especially for simulating grain sorting and bank erosion (Kadi Abderrezzak et al., 2014) which is the movement of organic or inorganic solid particles caused by gravity acting on the sediment and/or the movement of the fluid in which the sediment is entrained (UNESCO, 2021). A critical bed shear stress must be exceeded to start the particle movement. Particle threshold conditions need the consideration of several factors, including bed shear stress, critical velocity, cross-sectional shape, individual particle fall velocity, material size, and boundary conditions (Maleki, 2011). Most natural alluvial streams experience sediment mobility due to the exchange of momentum between the flow and the bed materials, which is heavily influenced by the occurrence of disturbance on the stream bed (Barman et al., 2019). One of the disturbances is coming from mining which is a type of manmade disturbance that can influence the characteristics of turbulence in the flow.

Figure 2.3 shows the Lane's Law illustration where the river is stable when all the water and sediment it receives without changing shape or pattern. There should be neither erosion nor deposition. The dynamic balance phenomenon was described qualitatively by Lane (1955). The concept of stream power and the relationship between the supply of water and sediments. Higher discharges and steeper slopes both increase stream power, but because slope decreases downstream as discharge increases, a mountain stream in flood generates far more power than a large lowland river, and a river that overflows its banks into the floodplain generates far less power than one that stays within its banks (Doty, 2022).

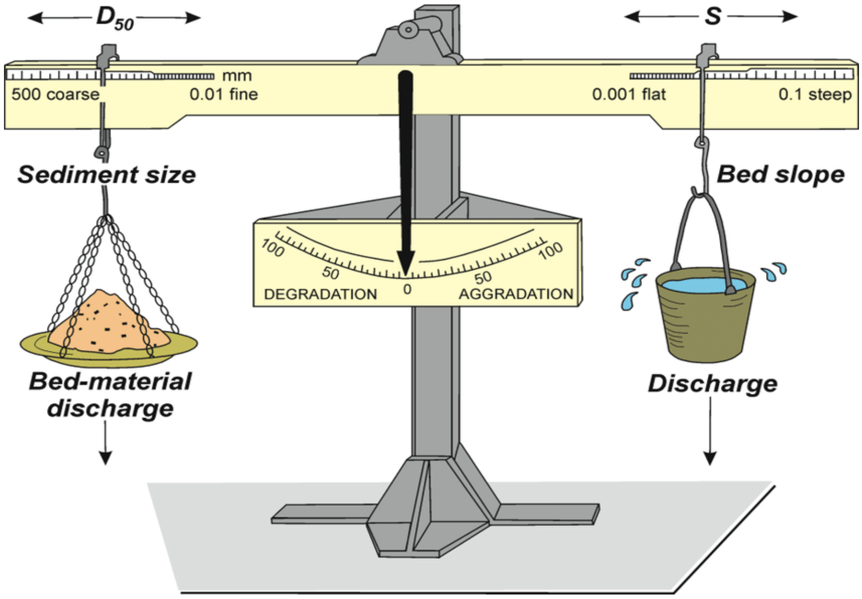

Figure 2.3: Lane's law illustrations

(Doty, 2022)

2.6 Modes of Sediment Transport

When the flow characteristics (velocity, average shear, stress, etc.) in an alluvial channel exceed the threshold condition for the bed material, particles move in a variety of modes along the flow direction, with the mode of transport dependent on sediment characteristics such as size and shape, density, and movability parameter (Ashraf et al., 2011). Some sediment particles roll or slide randomly over the bed, whilst others saltate (hopping or bouncing along the bed).

Figure 2.4 shows the modes of sediment transport include wash load, suspended load, and bed load. Rivers transport sediments as bed load, suspended load, and wash load. The coarsest materials roll or bounce along the bottom as bed load, while finer materials are suspended by water turbulence and the finest particles are delivered as wash load, which is evenly spread throughout the water depth and flows at the same rate as water (Komar, 1980). Bed load can range from a few percent of total load in lowland rivers to as much as 15 percent of total load in mountain rivers and as much as 60 percent of total load in some dry catchments. Typically, the rate of sediment transfer is a power function of flow, meaning that doubling the flow results in more than doubling the rate of sediment transfer, and most of the sediment transfer occurs during floods (Kondolf, 1997). The total load is the sum of the bed load, suspended load, and wash load.

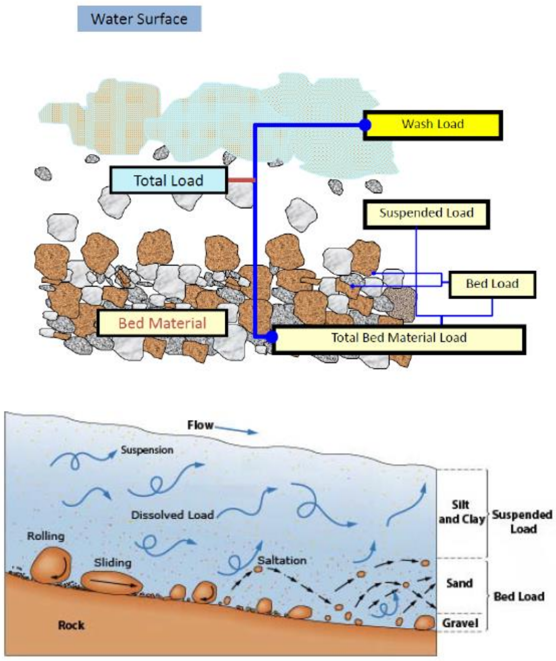

Figure 2.4: Modes of Transporting Sediment

(DID, 2010)

2.7 HEC-RAS

HEC-RAS was developed by the US Corporation Engineers Hydraulic Engineering Centre to simulate river flow. HEC-RAS can be used for a variety of types of river simulation studies, and for steady, unsteady, and mixed flow regimes (Agrawal and Regulwar, 2016). HEC-RAS enables users to predict the water surface profile along a river in steady and unsteady flow river hydraulic calculations, as well as sediment transport modelling (Zainalfikry et al., 2020). The HEC-RAS 1D model is widely used for sediment transport simulation (Joshi et al., 2019)

2.7.1 Quasi Unsteady Flow

The quasi-unsteady flow is an approximation of a hydrograph of continuous flow to a series of steady flow segments (Mohammad et al., 2016). Generally, unsteady models can be used to simulate unsteady fluvial processes as well as steady and quasi-steady processes. Thus, the boundary conditions between upstream and downstream can be chosen for simulation.

2.8 Total Sediment Load Equations

Sediment transport equations have been derived empirically and through laboratory measurements, and this equation is mostly suitable for laboratory concentrations and laboratory conditions (Ariffin et al., 2002). Total sediment transport in streams is classified into bed load transport and suspended load transport based on two different motion patterns in which the sum of bed load and suspended load is equal to the total load (Avgeris et al., 2020). Several total bed load material transport rate predictors have been developed by several investigators such as Sinnakaudan et al. (2006); Ariffin (2004); Molinas and Wu (2001); Karim (1998); Yang (1973,1984,1996); Ghani (1993); Raudkivi (1990); Karim and Kennedy (1983); Brownlie (1981); Yalin (1977); Ackers and White (1973); Graf (1968), Engelund and Hansen (1967); Garde et al. (1963) and Laursen (1958).

In this study, the Yang, Enguland-Hansen and Ariffin equations is chosen because these equations are recommended by the DID. Since the computation in the HEC-RAS can be made only using the Yang equation. Therefore, Yang equation is the most selected equation to be used in the study.

2.8.1 Yang (1973)

Yang (1973) formulated a total load transport equation based on stream power, the product of stream velocity and shear stress. Using a broad range of flume and field data, the function was constructed and assessed. The equation comprises three transport relations, including sand bed river, sand and silt bed river, and gravel bed river. In this study, however, just the sand bed river equation is employed. In the Malaysia sediment transport guideline, DID (2009) recommends this equation to assess sediment capacity. There is a recommendation from a previous study that the Yang equation was suggested for the natural river (Yenn Teo et al., 2017) not included with the wash load

$$\log C_{pt} = 5.435 - 0.286 \log\left(\frac{w_s d_{50}}{v}\right) - 0.457 \log\left(\frac{U^*}{w_s}\right) + \left[1.799 - 0.409 \log\left(\frac{w_s d_{50}}{v}\right) - 0.314 \log\left(\frac{U^*}{w_s}\right)\right] + \log\left[\left(\frac{VS_0}{w_s}\right) - \left(\frac{V_c S_0}{w_s}\right)\right] \quad \textbf{(2.1)}$$

For Re* = 1.15 – 70

$$\frac{V_c}{w_s} = \frac{2.5}{\left[\log\left(U_*\frac{d_{50}}{v}\right) - 0.06\right]} + 0.66$$

For Re* > 70

$$\frac{V_c}{w_s} = 2.05$$

where;

C_{pt} sediment concentration (in ppm by weight)

Re* shear Reynolds number = $\frac{w_s d_{50}}{v}$

w_s fall velocity of sediment (m/s)

d_{50} mean diameter of sediment (m)

n Manning number

U* shear velocity (√grs) (m/s)

S_0 slope of river profile

V_c unit stream power ((m-kg/kg)/s)

V_cS critical unit stream power required at incipient motion ((m-kg/kg)/s)

v kinematic viscosity (m^2/s)

2.8.2 Engelund-Hansen (1967)

Commonly used to evaluate the total bed material load, Engelund-Hansen (1967) is a total load transfer equation established from flume data using generally consistent sand particles between 0.19 mm and 0.80 mm (Naito et al., 2019). The derived equation is suitable for use in channels of uniform flow and cross section.

Some adjustments on the predicted values may be required if used on natural rivers. Previous research suggests that the Enguland-Hansen equation is suitable to subcritical rivers (Enguland et al., 1967) under conditions of low flow. This equation did not account for the wash load estimation of total load and instead was relied on the stream power approach. DID (2009) advises utilising the Eugelund-Hansen equation from 1967 to calculate how much sediment Malaysian rivers can transport.

$$q_s = 0.05(\gamma_s V^2)\left[\frac{d_{50}}{g\left(\frac{\gamma_s}{\gamma}-1\right)}\right]^{0.5}\left[\frac{\tau_0}{\left(\frac{\gamma_s}{\gamma}\right)d_{50}}\right]^{1.5} \quad \textbf{(2.2)}$$

where;

q_s sediment transport rate by weight per unit width (m^2/s)

γ specific weights of water (kN/m^3)

γ_s specific weights of sediment (kN/m^3)

V average velocity of river profile (m/s)

d_{50} mean diameter of sediment (m)

g acceleration due to gravity (m/s^2)

τ_0 shear stress (kg/m^2)

2.8.3 Ariffin (2004)

Ariffin (2004) is the local total sediment load equations that describe the capabilities of the equations on various rivers in Malaysia. Ariffin (2004) derived this equation using 346 data from 12 rivers in Malaysia. A set of sediment and hydraulic data consisting of 346 data by recent studies in Malaysia was used including by Ab. Ghani et al. (2003) and Ibrahim (2002). Based on the regression, the equation is generated. Ariffin has experimented with statistical methods like multiple linear regression, robust regression, and artificial neural networks (ANN). Multiple linear regression yielded the most accurate results for Malaysian rivers when compared to the other two. The equation suitable for sand bed river in Malaysia.

$$C_v = 1.156e^{-5}\left(\frac{R}{d_{50}}\right)^{0.716}\left(\frac{U*}{V}\right)^{0.507}\left(\frac{V^2}{gy}\right)^{0.524} \qquad \textbf{(2.3)}$$

where;

C_v sediment concentration (by volume)

R hydraulic radius

d_{50} mean diameter of sediment (m)

U* shear velocity (√grs) (m/s)

w_s fall velocity of sediment (m/s)

V average velocity of river profile (m/s)

g acceleration due to gravity (m/s^2)

y depth of river profile (m)

S_0 slope of river profile

2.8.4 Case Study 1

Assessment of Sediment Replenishment Volume in Langat River System

Mahmud et al., (2022) studied the ideal quantity of sand extraction in Langat River, Selangor, Malaysia, from 2016 to 2017. Changes in riverbed elevation at Langat River caused by sand mining are not the topic of this brief study. Consequently, sediment transport rates are calculated using current hydrological data. Based on a 25-year ARI flood, the measured water discharge (channel-forming discharge) is 540 m^3/s. The rate of sediment transport is equivalent to the river flow discharge. Yang's equation (1972) was used as the sediment transport equation for the study of 24 sediment size-averaged data sets (d50). As the ratio of the predicted load to the actual load, the discrepancy ratio (DR) was employed to evaluate the performance of the equation. As a standard for measuring the selected equations, the discrepancy ratio of 0.5 to 2.0 (DR = 0.5-2.0) was used. Yang's equations gave the best yielded percentage prediction of data sets within a discrepancy ratio of 0.5 to 2.0, which is 41.6 percent.

2.8.5 Case Study 2

Stable Channel Analysis with Sediment Transport for Rivers in Malaysia

Harun et al., (2020) studied the Kurau River (a small river), the Muda River (a medium-sized river) and the Langat River (a large river) using an analytical approach that modifies the stable channel flow chart created by Chang (1988) and Ariffin (2004). The conditions of three rivers in Malaysia were assessed using a stable channel flow chart. These rivers have different erosion rates. Discharge, bed and bank material, suspended load, bedload, and water surface slope were measured. Bedload sediment was sampled with a Helley-Smith sediment sampler and suspended load with a DH-48 depth-integrating sampler.

The equations utilised for Langat River, Muda River and Kurau River are listed in Table 2.1 with the percentage accuracy. The discrepancy ratio (DR) compares the calculated and measured total bed material load. The ideal range of DR is between 0.5 and 2.0 (Ariffin, 2004; Molinas & Wu, 2001; Sinnakaudan et al., 2006), and the correlation between the calculated and measured total bed material load should be 1. There are 214 sets of data.

Table 2.1: Equations Used and The Percentage Accuracy

Equations	**Locations**	**No. of Data**	**No. of Data (DR 0.5 – 2.0)**	**Percentage Accuracy (%)**	**Average Percentage Accuracy (%)**	**R^2**
Ariffin (2004)	Muda River	76	4	3.95	25.70	0.021
	Langat River	60	43	71.67		
	Kurau River	78	9	11.54		
Sinnakaudan et al., (2006)	Muda River	76	2	2.63	30.37	0.260
	Langat River	60	37	61.67		
	Kurau River	78	26	33.33		
Enguland and Hansen (1967)	Muda River	76	19	25.00	41.80	0.295
	Langat River	60	31	51.67		
	Kurau River	78	38	48.72		
Yang (1979)	Muda River	76	16	21.05	37.79	0.355
	Langat River	60	30	50.00		
	Kurau River	78	33	42.31		

2.8.6 Case Study 3

Sediment Transport Equation Assessment for Selected Rivers in Malaysia

Kiat et al., (2005) studied 122 sediment data collected in Kinta River Catchment between May 2000 and October 2002 as part of a river sediment collection and analysis. Six research sites consisting of four rivers within the Kinta River Catchment, namely the Kinta River, Pari River, Raia River, and Kampar River, have been utilised to gather data on suspended load, bed load, bed material, and flow discharge. Using the Yang, Engelund & Hansen, Ackers & White, and Graf equations, sediment transport equation evaluations have been conducted. This study incorporates the findings of Yahaya (1999) and Ariffin (2002) for Kerayong River, Kulim River, and Langat River basin (224 data sets).

Table 2.2 shows the summary of the equations used and the accuracy in percentage of the equations. The total of 346 data sets were generated to get discrepancy ratio within a range of 0.5 to 2.0. The assessment was based on the average size of silt grains (d_{50}). The result proves that the Yang and Engelund-Hansen equations provide a more precise prediction of observed data. For sand-bed rivers in Malaysia, the Yang and Engelund-Hansen equations can be used to estimate the sediment transport rate.

Table 2.2: Equations Used for Present Study Kiat et al., (2005) and Previous Study Yahaya (1999) and Ariffin (2004)

Equations	**Present Study by Kiat et al., (2005)**		**Yahaya (1999) and Ariffin (2004) Studies**		**All Data**	
	No of Data	Percentage Accuracy	No of Data	Percentage Accuracy	No of Data	Percentage Accuracy
Yang (1979)	22	18.03	60	26.79	82	23.70
Enguland and Hansen (1967)	30	24.59	46	20.54	76	21.97
Ackers and White (1973)	7	5.74	37	16.51	44	12.72
Graf (1968)	10	8.20	36	16.07	46	13.41

Thus, these three case studies show the frequent equations used by researchers for researching the best fit equation for Malaysia rivers. The studies have suggested Yang and Engelund-Hansen as equations with acceptable performance. Due to the similarities in sediment characteristics between China and Malaysia, where the most of upland erosions travelled from the loess region, the Yang equation may be used to estimate sediment rates in Malaysian rivers (Ghani et al., 2019). In this research, the Yang, Enguland-Hansen and Ariffin equations are the interested equations to be researched.