Journal of Water Resources Management, Vol. 3 No. 1 (2025) p. 1-6

JOWRM

Journal of Water Resources Management

Journal homepage: https://journal.water.gov.my

e-ISSN: 2811-3578

Quantifying Riverbank Erosion Based on Morphology: Case Study of Bernam River

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Received 13 March 2025;
Accepted 08 June 2025;
Available online 28 June 2025

Abstract: Erosion of riverbanks has far-reaching consequences, including changes to river shape and local habitat, destruction of riparian land, harm to buildings and other infrastructure, and a weakened capacity to withstand floods. The determination of which areas of a riverbank are susceptible to erosion is a crucial step in being able to forecast changes in the river's course and aid with stream management and restoration. This study assessed the magnitude of streambank erosion at three different channel morphologies which are straight, mild bend and extreme curve channel. The purpose of this research is to conduct fieldwork erosion monitoring of riverbanks, including those affecting hydraulic characteristic, bank geometry and soil properties. This is done so that the extent of riverbank erosion that occurs at natural rivers because of land use at locations upstream of the river. Erosion monitoring data provide measurements of erosion depth and riverbank cross-profiling across different channel morphologies. The total erosion lengths for the straight, mild bend, and extreme curve channels are 15.4 cm, 10.2 cm, and 10.2 cm, respectively. The highest erosion occurs in the straight channel, primarily due to the presence of natural groynes near the bank, which disrupt river velocity and lead to riverbed deterioration rather than direct riverbank erosion.

Keywords: Riverbank, erosion, channel morphology.

1. Introduction

In a geomorphic context, a riverbank is a landform identified by a topographic gradient that extends from the channel's bed along the lateral land-water boundary up to the greatest stage of flow or up to the topographic edge where water first starts to spread laterally across the surface of the floodplain. Two processes are involved for soil detachment along riverbanks: 1) hydraulic erosion caused by channel flow, and 2) subaerial erosion caused by the weakening and weathering of bank components (Abidin et al.,2017). This study provides a comprehensive understanding regarding factors that contribute to bank erosion as a result of extensive deforestation, hydraulics, and the vegetation that is present. Aside from that, a recommendation for restoration work and continuous assessment of the deteriorating bank can be made. This is significant as controlled bank erosion can lead to improving water quality of the river and reduce the chance of flooding of the river due to river carrying capacity.

In this study, we assessed the magnitude of streambank erosion with different channel morphologies which are straight, mild bend and extreme curve channel. In order to measure the erosion at the bank, field investigation has been conducted to determine erosion depth and length, hydraulic characteristic, bank geometry and soil properties of Bernam River under variation of channel morphology. Sungai Bernam is one of the rivers whose banks are prone to being eroded due to the land use along the bank and deforestation at the upstream. From the data measured, mathematical functions, namely polynomial functions, are used to establish the relationship between erosion depth and near bank velocity at each channel morphology along Bernam River. Our specific objectives are to (1) assess the magnitude of streambank

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erosion at different channel morphology, (2) measures erosion depth and length, hydraulic characteristic, bank geometry and soil properties of Bernam River under variation of channel morphology, and (3) develop relationship between erosion depth and near bank velocity at the channel morphology.

2. Methodology

This section covers the overall methodology (Fig. 1) used in this study to meet the objectives, namely, (i) location selection, (ii) fieldwork erosion data, (iii) relationship equation, (iv) result and discussion, and (v) conclusion and recommendation. This study utilizes data from three (3) types of channel morphology along Bernam River which are straight, mild bend and extreme curve channel. Variables recorded include erosion depth (cm), average velocity (m/s), bank height (m)and mean size particles, D_{50}.

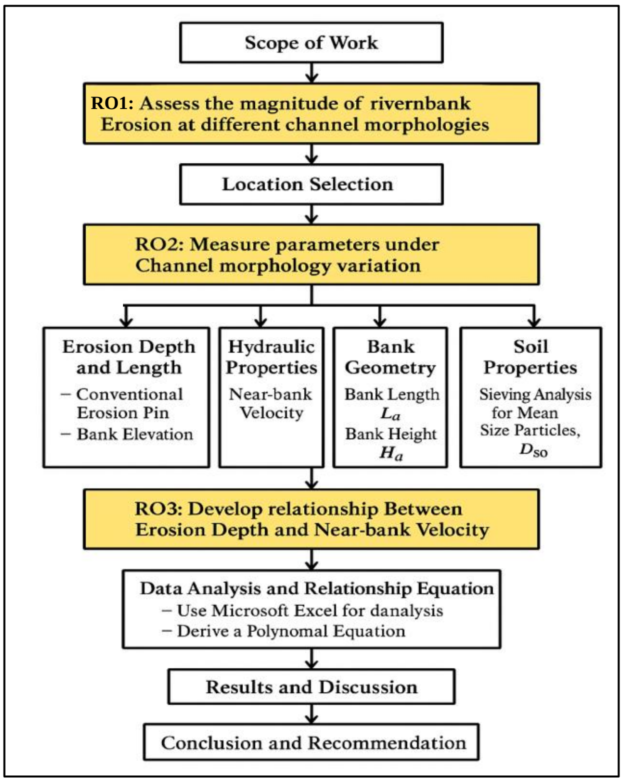

Fig. 1:Flowchart of the overall methodology

2.1 Site Location

The research area for the assessment of riverbank erosion is the Bernam River, which acts as a natural barrier between the Malaysian states of Perak and Selangor that located at latitude 3°51.02 N and longitude 100°50.15 E. The Bernam River basin covers an area that is 2836.33 km^2 in total. It flows from the upstream of Mount Triang Timur, which is situated to the east of Mount Titiwangsa, and continues all the way to the Straits of Malacca, which is located to the west. In the upper part of the basin, vegetation covers such tropical hill rainforests, oil palm trees, and rubber trees dominate. The Bernam River is one of the rivers whose banks are susceptible to erosion, transport and deposition as a result of the land usage along the bank and the deforestation that has occurred upstream of the river. In this study, research is carried out at three different channel morphologies of the river. These morphologies of the river are referred to as a straight river, a mild bend, and an extreme curve. The site location for all channel morphology as shown in Fig. 2.

Fig 2: Site location for study area

2.2 Fieldwork Measurement

Measurements taken in the field of the river include the riverbank erosion rate, the hydraulics characteristics, the bank geometry, and the soil parameters. In accordance with Lawler's (1993) recommendations, the erosion pin method is utilized in order to determine the magnitude at which the riverbank is being eroded. The location for erosion pin transects determined according to the critical of the bank erosion. 10 pins were installed at each channel morphology with a total of 30 pins used in this study. According to Mohd Rosli et al., (2021), the length of the pins is determined by the estimated rates of erosion as well as the number of times that the location is visited. The total length of the pins is 35 cm and 6 mm diameter of mild steel and placed perpendicular to the bank until 30 cm of the pin are placed in the riverbank with the spacing 30 cm between each pin as illustrated in Figure 3.

A gauging method that is consistent with the Drainage and Irrigation Department's Hydrological Procedure No. 15 (1976), reprinted (1995) has provided a recommended guideline for wading technique as demonstrated in Figure 4. For measuring stream depth, d, between 0.25 m and 1 m, a measurement of 0.6d from the water surface is appropriate, whereas for measuring depth, d, between 1 m and 1.5 m, a reading between 0.2d and 0.8d from the water surface is suggested. For this study, the current flow meter for river is used to take the reading of the river velocity. This research employs the measurement of near-bank velocity in a manner similar to Saadon et al. (2021), which was adapted from Hasegawa (1989). In this approach, near-bank velocity is measured at a horizontal distance of 1 meter from the eroded bank, rather than using the stream-averaged velocity (u), to better assess its role in regulating bank erosion or accretion.

One of the ways to determine the geometry of a riverbank is to take measurements of the bank height. The height of the bank is an essential measure to take since the information they provide is important to the erosion and stability of the bank. A high and steep bank is likely to be unstable and commonly demonstrates susceptibility to erosion, cantilever failure, and collapse. A measuring tape was used to provide an accurate reading of the height.

Fig. 3: Erosion pins installed subjected to extreme curve channel after 30 days of installation

Fig. 4: Wading technique using Current Flow Meter

2.3 Laboratory Testing

Sieve analysis is a basic method used to determine the particle size distribution of granular materials such as soil, sand, aggregates, and powders. It involves passing the material through a series of sieves with progressively smaller mesh sizes and measuring the amount of material retained on each sieve. This method is in accordance with BS 1377: Part 2, which specifies the following sieve sizes: 4.75 mm, 2mm, 1.18mm, 0.6mm, 0.425mm, 0.212mm, 0.15mm, and 0.075mm. The soil sample was collected at Bernam River to determine the mean particle size of the D_{50} of the soil.

3. Results and Discussion

3.1 Hydraulic Data

The near-bank velocity of the channel is included is part of the hydraulic properties of the data that are measured. Velocity of the water flowing near to the bank measured at a horizontal distance of 1 m from the bank erosion, at depth 0.2D, 0.6D and 0.8D at each studied morphology. The data of the near bank velocity, u_b are tabulated in Table 1. For all channel variations, the reading for the velocity near the bank was obtained from the 1st April 2023 to the 13th May 2023. According to the data presented in Table 1, the average velocity for the straight channel ranges from 0.795 to 1.488 m/s. On the other hand, the average velocity for the mild bend channel is between 0.66 and 1.141 m/s, and the average velocity for the extreme curve channel ranges from 0.895 to 2.915 m/s.

Table 1: Near-bank velocity at Sungai Bernam at different channel morphologies

River Morphology	Date	Flow Velocity, u_b (m/s)			
		0.2D	0.6D	0.8D	Average
Straight	1/4/2023	1.898	1.577	0.988	1.488
	4/4/2023	1.582	1.475	1.768	1.608
	8/4/2023	1.848	0.648	1.021	1.172
	6/5/2023	0.974	0.854	0.648	0.825
	13/5/2023	0.915	0.968	0.501	0.795
Mild bend	1/4/2023	0.995	0.941	-	0.968
	4/4/2023	0.812	0.508	-	0.660
	8/4/2023	1.261	1.021	-	1.141
	6/5/2023	1.235	1.342	0.621	1.066
	13/5/2023	1.155	1.075	-	1.115
Extreme curve	1/4/2023	1.715	0.588	0.381	0.895
	4/4/2023	2.134	0.914	-	1.524
	8/4/2023	2.542	0.781	0.461	1.261
	6/5/2023	3.395	2.435	-	2.915
	13/5/2023	2.468	1.422	0.408	1.433

3.2 Bank Geometry

The measurements of bank length, bank height, and bank angles represent the riverbank geometry data. Table 2 provides a summary of data regarding riverbank geometry under variation of channel morphology along Bernam River. The bank angle for a straight channel is 54.38˚, while the bank angle for a mild bend channel is 58.35 degrees, and the bank angle for an extreme curve channel is 71.97˚. All the channel morphologies have a bank slope that is greater than 45˚, which indicates that the bank has a very steep slope. Possible riverbank erosion and instability are due to the steepness of the slopes. Riverbanks of this sort are typically susceptible to rapid erosion, particularly during high flow events and other forms of factors that contribute to erosion.

Table 2: Riverbank geometry for various morphology of Bernam River

		Riverbank Geometry		
River Morphology	Date	Bank Length, L_b (m)	Bank Height, H_b (m)	Bank Angle, Ø (˚)
Straight	1/4/2023	4.45	3.26	54.38
	4/4/2023	4.45	3.26	54.38
	8/4/2023	4.45	3.26	54.38
	6/5/2023	4.45	3.26	54.38
	13/5/2023	4.45	3.26	54.38
Mild Bend	1/4/2023	3.9	3.32	58.35
	4/4/2023	3.9	3.32	58.35
	8/4/2023	3.9	3.32	58.35
	6/5/2023	3.9	3.32	58.35
	13/5/2023	3.9	3.32	58.35
Extreme Curve	1/4/2023	2.85	2.71	71.97
	4/4/2023	2.85	2.71	71.97
	8/4/2023	2.85	2.71	71.97
	6/5/2023	2.85	2.71	71.97
	13/5/2023	2.85	2.71	71.97

The samples of soil were obtained from the riverbank located at Bernam River with different types of channels

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morphologies which are straight, mild bend and extreme curve of river. The characteristics of the soil are indicative of the soil composition that existed along the riverside. The experiment was carried out using a test known as a sieve analysis, in which a sample of soil is dried in dried for 24 hours and then weighing it before being placed in a sieve shaker. The purpose of the experiment was to determine the mean particle size at the D_{50}. For straight channel, a sample of 1,000 g of soil at riverbank are taken for the sieving. As a result, the particles that could be found in each sieve were measured and recorded. Following completion of the sieve analysis test, the particle size distribution is depicted in Fig. 6 below. The mean particle size at D_{50} is 1.00 mm, which is classified as very coarse sand. For the mild bend channel morphology, a sample weighed 1,500 g were placed into the sieve. After sieving in the mechanical shaker for 10 minutes, the particles retained in each sieve were measured and recorded. The graph of the particle size distribution that was produced after carrying out the sieve analysis test may be found in Fig. 5. The average particulate size at D_{50} is 2.5 mm, which classifies the material as gravelly sand soil. A 1,000 g sample was weighed and placed in the sieve to represent particle size of the extreme curve channel morphology. Following the sieving process that took place in the mechanical shaker for 10 minutes, the particles that were retained in each sieve were measured and documented. Fig. 7 displays the graph of the particle size distribution that was obtained as a result of carrying out the sieve analysis test. The particle size for extreme curve bank is a coarse sand since the average particle size at D_{50} is 0.95 mm.

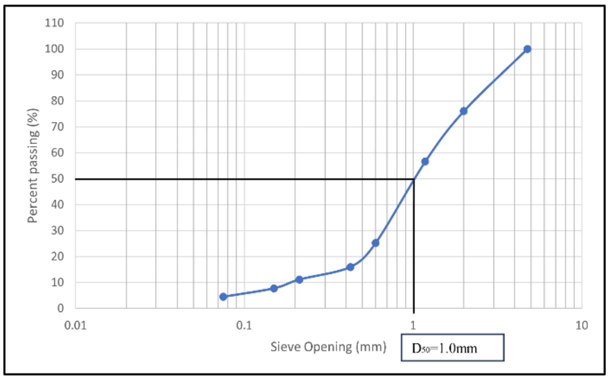

Fig. 5: Particle size distribution for straight channel morphology

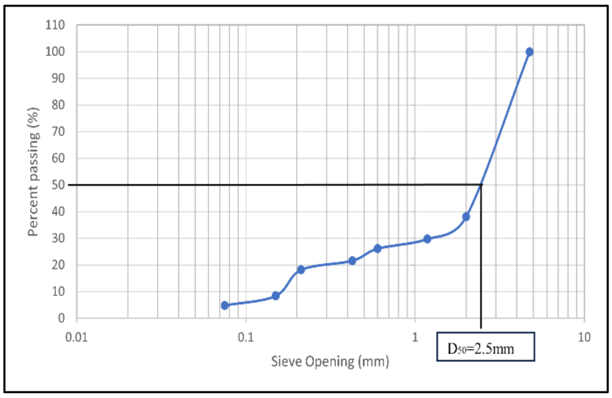

Fig. 6: Particle size distribution for mild bend channel morphology

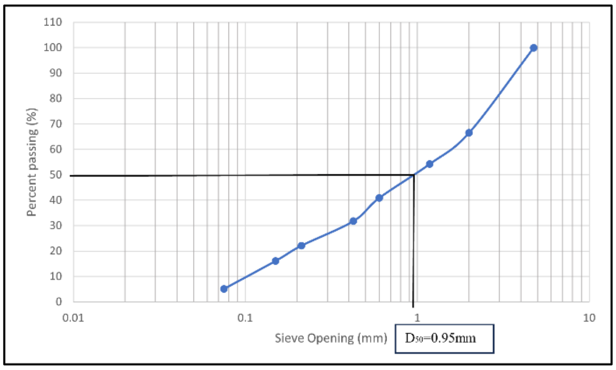

Fig. 7: Particle size distribution for extreme curve channel morphology

3.4 Erosion Pin

The erosion pin method is appropriate for short timescale measurements of up to a year in length. Pins are an accurate and cost-effective alternative to other methods for assessing bank retreat due to river action and soil failures. A total of 30 erosion pins as shown in Table 3 were set along the riverbank, which featured three distinct morphologies: a straight section, a section with a mild bend, and a section with an extreme curve. The erosion pin is a steel rod that is 35 cm long, has a diameter of 6 mm, and is driven into the ground in a direction that is perpendicular to the riverbank face with the distance for each pin is 30 cm. These pins were placed leaving a distance of 5 cm exposed. All of the readings were carried out over the course of 42 days, beginning on April 1, 2023, and ending on May 13, 2023.

Table 3: Numbers of erosion pin installed along Bernam River

Field site	Channel Morphology	No. of pins
Sungai Bernam	Straight	10
	Mild Bend	10
	Extreme Curve	10

Erosion pin readings were recorded in cm, at the end of each monitoring period. The results of Sungai Bernam's erosion pin readings during the monitoring period are presented in Table 4. Based on the data collected from the erosion pin arrays, it was determined that the straight channel incurred the most erosion. This is due to the fact that there are existing groynes along the riverbank at the straight channel. These groynes influence the discharge of water near the riverbank. For May 13, 2023, the total length of erosion at straight, mild bend, and extreme curve was 15.4 cm, 10.2 cm, and 10.2 cm, respectively. The evidence suggests that most of the erosion took place in channels that were straight, and the range of the erosion that took place within this morphology is from 0.2 cm to 3.6 cm.

Table 4:Erosion depth reading by erosion pin method under various channel morphology

Date	Accumulative erosion (cm)	Average erosion (cm)
Straight Channel		
4/4/2023	0.8	0.2
8/4/2023	2.4	0.4
6/5/2023	10.7	1.34
13/5/2023	18.5	1.85
Mild Bend Channel		
Date	Accumulative erosion (cm)	Average erosion (cm)
4/4/2023	3.6	0.9
8/4/2023	6.2	1.03
6/5/2023	9.8	1.23
13/5/2023	10.2	1.46
Extreme Curve Channel		
Date	Accumulative erosion (cm)	Average erosion (cm)
4/4/2023	3.2	1.6
8/4/2023	4.5	1.5
6/5/2023	9	1.29
13/5/2023	10.3	1.47

3.5 Relationship Between Erosion Dept and Near -Bank Velocity

It was determined that there is a correlation between depth of erosion and velocity near the bank through a polynomial function. Fig. 8 to 10 illustrate the relationship between rate of erosion and near bank velocity. It has been found that the polynomial function provides an excellent correlation for different types of channel morphology. The equation derived from these functional relationships then can be used to develop the erosion rate relationship for other rivers with the same type of morphology

The R^2 value for straight channel has the best correlation between the variable of the average erosion depth and near bank velocity at R^2= 0.9837 for polynomial function. The strong correlation value, R^2= 0.9235, is also given by the polynomial function for the extreme curve channel. Furthermore, the correlation for the mild bend channel indicates a moderate relationship, with an R^2 value of 0.6017, as presented in Table 5. In this correlation, y represents the average erosion depth (cm), while x denotes the near-bank velocity (u_b) in m/s.

Table 5: The relationship equation and R-squared for each channel morphology at Bernam River

No.	River Morphology	Equation	R-Squared
1.	Straight	$y = 3.5866x^2 - 10.399x + 7.6061$	0.9837
2.	Mild Bend	$y = 17.626x^2 - 30.568x + 13.37$	0.6017
3.	Extreme Curve	$y = -1.4401x^2 + 6.0726x - 4.1833$	0.9235

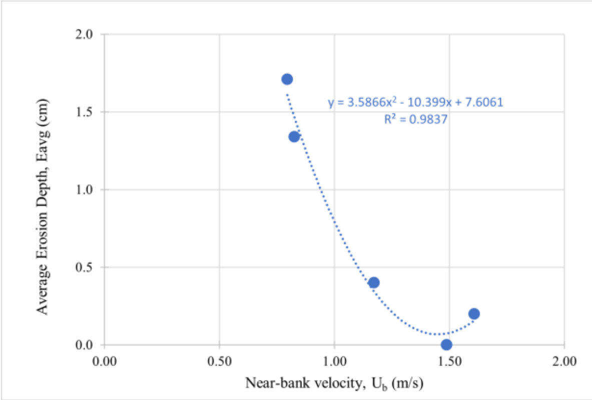

Fig. 8: Erosion depth and near bank velocity relationship for straight channel at Bernam River using polynomial function

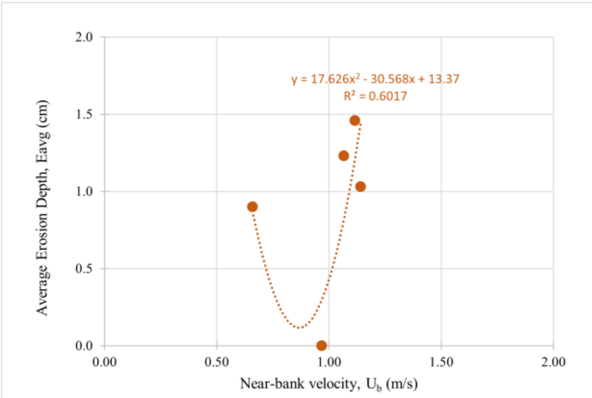

Fig. 9: Erosion depth and near bank velocity relationship for mild bend channel at Bernam River using polynomial function

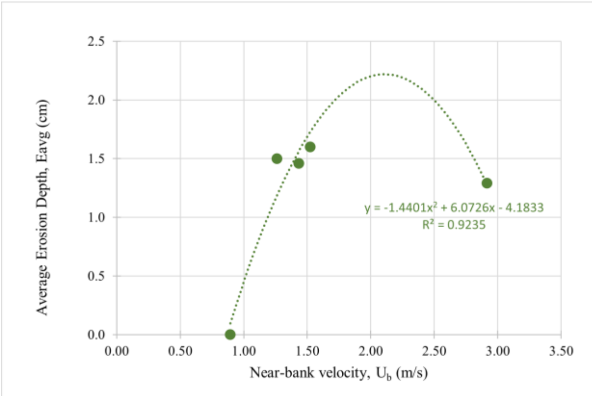

Fig. 10: Erosion depth and near bank velocity relationship for extreme curve channel at Bernam River using polynomial function

4. Conclusion

This study was successfully conducted to highlight the best practice approach to establish relationship between near bank velocity and average erosion depth for Bernam River. The relationship for these two variables is derived using mathematical functions, namely polynomial function. The degree of accuracy of the function was evaluated in terms of the statistical parameters. Mathematical expression represented in polynomial function yields accuracy of at least 0.6017. Although straight channels have the highest accuracy at 0.9837, the relationship between erosion depth and near bank velocity does not satisfy the scenario since the rate of erosion decreases as velocity increases. The erosion occurs at the riverbed instead of riverbank due to existing groyne at the channel. However, the correlation can be satisfied by channels with either a mild bend or an extreme bend since the rate of erosion and the velocity exhibit a linear relationship. In addition, according to observations made in the field, the rate of riverbank erosion appears to be most influenced by the flow velocity.

Acknowledgement

The authors would like to extend their gratitude to the School of Civil Engineering, College of Engineering, Universiti Teknologi MARA for providing the necessary facilities to conduct this research. My gratitude and thanks also extend to the supervisor Ts. Dr. Azlinda Saadon for her invaluable guidance, encouragement, and support throughout this project. The further acknowledgement Norhidayah Zakaria, Nurul Afiqah Mohd Anuar, and Nurul Nazihah Mat Zaidi for assistance in collecting data.

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