Morphometric Analysis of the Pahang River Basin and Its Sub Basin System at Pahang State, Peninsula Malaysia

Mohd Aliff Mohd Anuar
Universiti Tun Hussein Onn Malaysia

Mohd Shalahuddin Mohd Adnan
Universiti Tun Hussein Onn Malaysia

Mohamad Hafiz Hassan
Department of Irrigation and Drainage Malaysia

Mohd Sofiyan Sulaiman
Universiti Malaysia Terengganu

他

https://doi.org/10.5109/7323362

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.868-873, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

Morphometric Analysis of the Pahang River Basin and Its Sub Basin System at Pahang State, Peninsula Malaysia

Mohd Aliff Mohd Anuar[1,3], Mohd Shalahuddin Mohd Adnan[1], Mohamad Hafiz Hassan[2], Mohd Sofiyan Sulaiman[4]
Nurul Hidayah Ruslan[5]
[1]Universiti Tun Hussein Onn Malaysia, [2]Department of Irrigation and Drainage Malaysia, [3]Minconsult Sdn. Bhd.
[4]Universiti Malaysia Terengganu, [5]Universiti Teknologi MARA Malaysia.
Corresponding author email: mohdaliffmohdanuar@gmail.com

Abstract: *This study evaluates the catchment characteristics of the Pahang River Basin and its sub-basins in Pahang state, Peninsular Malaysia, utilizing GIS techniques and IFSAR-DEM data. Parameters such as stream order, shape, steepness, branching, dissection, and watershed elongation were analyzed to offer foundational insights into the basin's morphology and hydrological processes. These insights are crucial for development, management, and conservation planning. Notably, the Jelai, Lower Pahang, and Tembeling basins play a significant role in contributing runoff downstream, with dendritic patterns and moderate bifurcation ratios observed. The ongoing erosion and deposition processes, particularly in the meandering sections of the Pahang River, emphasize the dynamic nature of this landscape. These findings highlight the critical role of morphometric analysis in sustainable catchment management. Future research should further explore the spatial and relief aspects of the Pahang River basin, as well as its textural, material, and permeability characteristics, to inform and enhance watershed management strategies*.

Keywords: Hydrological Processes, Stream Order, River Morphology, Morphometric Analysis, Linear Aspect

1. INTRODUCTION

Morphometric analysis is a critical tool for understanding the distribution and characteristics of river basins. It involves the measurement and mathematical analysis of the surface, shape, and dimensions of the earth's landforms [1]. This approach can be applied to any large region, specific landform, or drainage basin, offering insights into various basin characteristics through the study of linear, areal, and relief aspects [2] [3]

Linear aspects focus on one-dimensional parameters such as stream order, stream number, stream length, and bifurcation ratio. Areal aspects involve two-dimensional parameters like form factor, drainage density, and stream frequency, while relief aspects deal with three-dimensional parameters, including slope, relief, relief ratio, and gradient ratio[4] Assessing these morphometric parameters for drainage basins can be efficiently accomplished using Geographical Information System (GIS) techniques. Geospatial technologies provide accurate information, rapid processing, and cost-effective evaluation of drainage basins, making them essential for modern hydrological studies.

Understanding the hydrological characteristics of steeply sloping areas is crucial for effective conservation efforts. Quantifying drainage basin characteristics and assessing the influence of deformational and erosional properties on the landscape are essential for geomorphometric studies [5] [3] Various morphometric indices offer insights into hydrological processes such as basin travel time, lag time, flooding, erosion, and deposition [6] [7] [2] [3].

The analysis of linear aspects of the selected basin morphometric parameters was conducted using established formulations by [8][9] [10] [11]. Despite the extensive application of morphometric analysis in various river basins globally, there is a notable research gap in the detailed morphometric characterization of the Pahang River Basin, one of the most significant river systems in Peninsular Malaysia. Previous studies have primarily focused on general hydrological assessments, but a comprehensive morphometric analysis integrating GIS technology for detailed catchment demarcation and evaluation has not been extensively explored. The main objective of this study is to compute and analyze various morphometric characteristics of the Pahang River Basin and its sub-basins using a GIS approach, to gain a deeper understanding of the basin's hydrological processes and characteristics.

This study fills the research gap by offering a detailed morphometric analysis that addresses the need for sustainable development, management, and conservation planning in the region. The novelty of this work lies in its integrated approach, combining GIS techniques with detailed morphometric analysis of the Pahang River Basin. This study not only provides a foundational understanding of the basin's morphology but also introduces new insights into the hydrological dynamics of steeply sloping areas, with a particular focus on the impacts of erosion and deposition processes. The findings are expected to contribute significantly to the development of more effective watershed management strategies in the region.

2. STUDY AREA

Nestled within Malaysia's largest state of Pahang, the Pahang River Basin spans a vast area defined by geographic coordinates ranging from 101° 30' E to 103° 30' E longitude and 3° 00' N to 4° 45' N latitude. Fig. 1 depict the Pahang River basin. Covering a total catchment area of 28,682 km², this basin features a diverse topography shaped by prominent geographical features. These include the rugged Titiwangsa Range to the west, the Tahan Range in the central north, and the East Coast Range in the northeast, each contributing unique elevation profiles ranging from 1,000 m to 2,180 m [12].[13]

The morphometric characteristics of the Pahang River Basin reveal distinct features across its landscape. The upper catchment area is marked by steep slopes, while the lower basin transitions into predominantly flat, swampy terrain. Central to the basin's hydrology is the Pahang River, spanning 459 km from its origin at the junction of the Jelai and Tembeling rivers in the Titiwangsa Mountains before emptying into the South China Sea.[13][14]

The basin experiences a tropical monsoon climate, characterized by a significant wet season from November to March, influenced primarily by the northeast monsoon. Rainfall patterns exhibit notable variability across the basin, with annual averages ranging from 1609 mm in Temerloh to 2132.36 mm in Lubuk Paku, underscoring the spatial distribution of precipitation [15].[16]This portrayal emphasizes the unique morphometric features and hydrological dynamics of the Pahang River Basin, providing a foundational context for detailed morphometric analysis

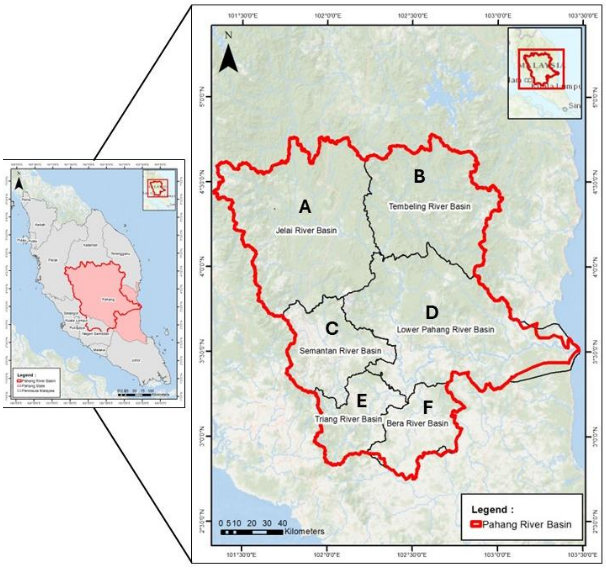

Fig. 1. Study Area

Table 1. River Basin ID

Basin Id	River Basin
	Pahang
A	Jelai
B	Tembeling
C	Semantan
D	Lower Pahang
E	Triang
F	Bera

3. METHODOLOGY

The evaluation of drainage network characteristics and basin demarcation were performed to calculate the morphological parameters using the datasets described below. Initially, we obtained a Digital Elevation Model (DEM). The DEM was then utilized to delineate the basins and define the stream network.

3.1 Digital Elevation Model

The High-resolution Digital Elevation Models (DEMs) were generated using raster data with 30-meter resolution Interferometric Synthetic Aperture Radar (IFSAR) obtained from the Department of Irrigation and Drainage Malaysia. These DEMs were utilized to identify and automatically extract the drainage network in the study area.[17] [18].To create a unified scene covering the entire study area, the images were resampled, re-projected, and mosaicked using the ellipsoidal oblique Mercator projection introduced by Hotine, also known as the rectified skew orthomorphic (RSO) Peninsular Malaysia projection in Geocentric Datum of Malaysia (GDM 2000). Following mosaicking, the entire scene was clipped to fit the boundary of the study area.

3.2 Stream Network Extraction and Basin Demarcation

To analyze the stream network, hydrology stream order tools available in ArcGIS 10.5.1 and the ArcSWAT tool were utilized. The extracted stream networks were used to delineate water catchments within Pahang River Basin and its sub basin and determine the number of catchments. The IFSAR-DEM was employed to delineate the Pahang River Basin and its sub-basins using hydrology tools within the Spatial Analyst extension. Basin demarcation starts by identifying the stream network and the highest elevations surrounding these networks. Divisions are then established between each stream network that terminates at a confluence.

3.3 Morphometry Measurement

The linear features of the basin extracted from the DEM were quantified using established mathematical formulas (refer to Table 2). These parameters included stream order (hierarchical rank), stream number, stream length, and bifurcation ratio.

Table 2. Description of linear morphological parameters of a basin [19]

Morphometric Parameter	Formula	References
Stream order (u)	Hierarchical order, where u = order number	Strahler (1957)
Stream orders (Nu)	Nu=N1+N2+…+Nn where Nu = total number of stream segment of order u	(Robert E Horton, 1945)
Length of stream orders (Lu)	Lu= L1+L2+…. +Ln where Lu = total stream length of order u	(Robert E Horton, 1945; Strahler, 1964)
Bifurcation Ratio (Rb)	Rb=Nu/Nu+1 where Nu+1 = next segment of higher order	(Schumm, 1956; Strahler, 1964)
Mean bifurcation ratio (Rbm)	$Rb_n = \frac{\frac{N1}{N2}+\frac{N1}{N2}+\cdots+\frac{N_n-1}{N_n}}{n-1}$	(Strahler, 1957)

3.4 Stream Order (u)

A stream begins as 'first order' at its source. When two first-order streams converge, they create a second-order stream. Similarly, the merging of two second-order streams results in a third-order stream, and so forth [3]. Stream order serves as a classification method that identifies streams based on the number of tributaries they possess [20]

3.5 Stream Number (Nu)

After assigning stream orders, the total number of streams for each order was calculated. The number of streams (Nu) decreases sequentially as the stream order increases [2]

3.6 Stream Length (Lu)

The length of each stream was determined using ArcGIS 10.5.1. For instance, the length of a second-order stream was measured from its origin at the confluence of two first-order streams to where it joins another stream of equal or higher order.

3.7 Bifurcation Ratio (Rb)

The bifurcation ratio (Rb) represents the ratio of the number of streams of a particular order to the number of streams in the next higher order. It provides insight into the branching pattern and hierarchy within the stream network, indicating how streams divide as they progress downstream [4].

4. RESULTS AND DISCUSSION

The DEM and basin demarcation was generated by using IFSAR data accordingly. Fig. 2 and Fig 3 depicts the DEM and demarcated basin for Pahang River basin and all the sub basins. The lowest and highest elevation for all the basin was tabulated in Table 3.

Table 3. Minimum and Maximum Elevation

River Basin	Minimum Elevation (m)	Maximum Elevation (m)
Pahang	0.0	2181.0
Jelai	44.0	2077.0
Tembeling	44.0	2181.0
Semantan	28.0	2052.0
Lower Pahang	0.0	2090.0
Triang	28.0	1436.0
Bera River	21.0	768.0

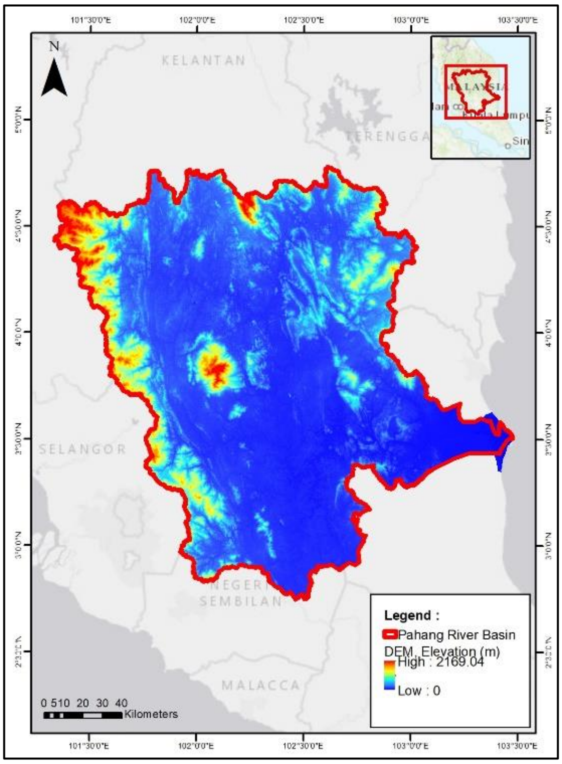

Fig. 2. Pahang River Basin DEM

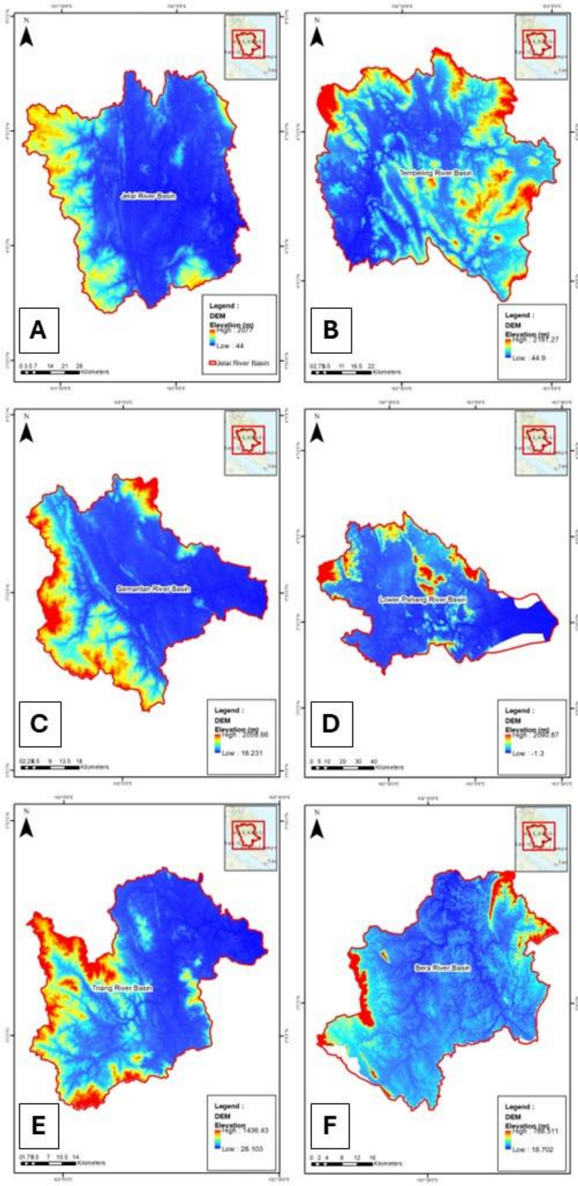

Fig. 3. Sub Basin DEM

Pahang river have a basin area of 28,680.28 km^2 consisting of 6 main sub basin respectively. Jelai river has the biggest sub basin area of 8,145 km^2, followed by Lower Pahang River (8,053 km^2), Tembeling River (5337 km^2), Semantan River (2,885 km^2), Bera River (2,160 km^2) and Triang River (2,053 km^2). The total basin perimeter, basin length and main channel length was stated in Table 4.

Table 4. Specifications adopted for simulated inverter

River Basin	Area (km^2)	Total Basin Perimeter (km)	Basin Length (km)	Main Channel Length (km)
Pahang	28680.2865	1202.23	1162.27	473.24
Jelai	8145.09	561.35	564.24	173.37
Tembeling	5337.62	433.15	439.22	185.14
Semantan	2885.742	323.90	313.41	146.44
Lower Pahang	8053.67	601.84	573.88	328.57
Triang	2053.37	294.56	259.03	121.30
Bera	2160.09	279.00	269.76	88.99

The Pahang River basin reaches fifth order level at the rivermouth in Pekan. Streams in the Pahang River basin and all the sub basin range for first order to fifth order (Fig. 4 and Fig. 5). In general, a higher stream order within a river basin suggests ongoing erosion of the topography, whereas a lower stream order indicates a more mature topography.[21] posited that higher stream orders correspond to increased discharge within the streams. This hierarchical ordering reflects a doubling of mean discharge capacity when two streams of the same order merge to form the next higher order stream. Thus, the Pahang River, Jelai River, Tembeling River, Semantan River, Triang River, and Bera River significantly contribute to discharge, potentially leading to increased erosion of river beds and banks. [9] categorizes headwater or mountainous rivers as having stream orders from first to fourth. Streams up to the third order are classified as headwater streams, while medium-sized streams range from the fourth to the sixth order. Streams with orders greater than the sixth are categorized as rivers.

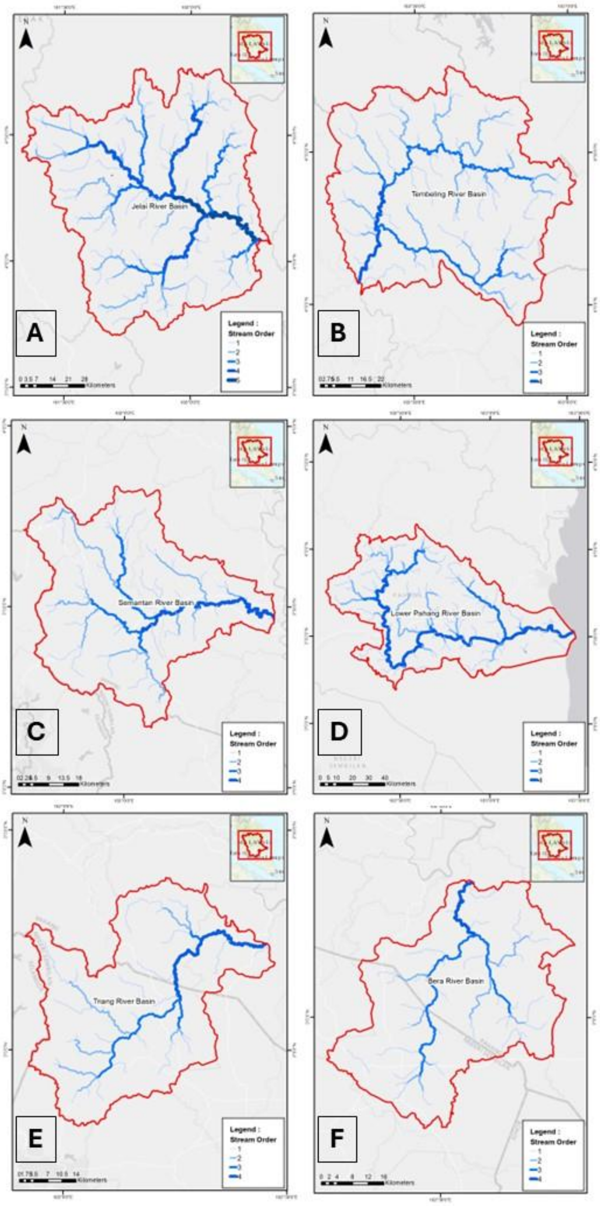

Fig. 4. Sub Basin Stream Order

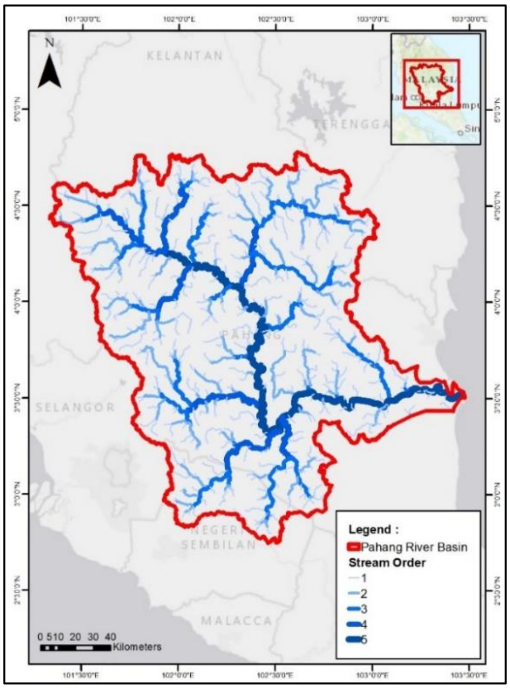

Fig. 5. Pahang River Basin Stream Order

Table 5. Linear Aspect Parameter

River Basin	Stream Order	Stream Number	Length of Stream (m)
Pahang	1	474	2797438.60
	2	117	1351266.76
	3	27	760595.32
	4	7	433443.37
	5	1	367723.94
	Total	626	5710468.00
Jelai	1	127	787485.70
	2	34	368027.49
	3	10	201558.21
	4	3	180009.42
	5	1	67204.03
	Total	175	1,604,284.86
Tembeling	1	89	480749.86
	2	21	341067.39
	3	3	196302.43
	4	1	50188.12
	Total	114	1068307.80
Semantan	1	49	260714.32
	2	14	189473.19
	3	3	82754.52
	4	1	76229.80
	Total	67	609171.83
Lower Pahang	1	133	843661
	2	28	315144
	3	7	147503
	4	1	256560
	Total	169	1562868
Triang	1	34	203982.81
	2	8	85869.70
	3	3	52401.20
	4	1	54225.98
	Total	46	396479.68
Bera	1	41	219597.32
	2	11	71379.16
	3	2	83725.96
	4	1	24168.33
	Total	55	398870.78

The total number of streams in the study area is 626, sub basin with highest streams numbers is Jelai Basin which 175 numbers, followed by Lower Pahang Basin with 169 numbers. Triang river has the lowest streams numbers. In the all basin, whether by number or length, half of all streams are first order. Elsewhere, the predominance of first-order streams has been interpreted as suggesting uniform underlying lithology and no apparent uplift in the basin [22]

Typically, the total stream length of first-order streams is the highest and diminishes with increasing stream order as stated in Table 1. The total stream length of all sub basin is 5,640 km. The decrease in total stream length as stream order increases conforms to the hydrological patterns outlined by Horton (1945). Various factors contributing to such deviations may include the geological formations, moderately steep slopes, and high-altitude origins of the streams [23]. The Jelai, Tembeling, and Lower Pahang basins exhibit greater hydrological activity compared to the Semantan, Triang, and Bera basins due to their higher number of streams, which directly correlates with longer travel times.

The shape of the basin can be assessed using the mean bifurcation ratio (Table 6). A basin with a high Rb indicates an elongated shape, whereas a basin with a low Rb suggests a more circular shape. The mean Rb value for all basin stated moderate bifurcation ratio suggests a balance between the number of streams at different orders, often indicating a mix of dendritic and parallel drainage patterns. The shape of a catchment impacts the dynamics and propagation of floods. In elongated catchment areas with higher mean Rb values, floodwaters travel faster, potentially intensifying downstream flood events. A higher Rb value signifies a more pronounced structural influence on the drainage system, whereas a lower Rb indicates lesser geological impact on the catchment or sub-catchment. Mean Rb values suggest minimal structural disturbance and less distortion of the overall drainage system [4].

Table 6. Bifurcation Factor

Stream Order	Bifurcation Factor	Mean Bifurcation Factor
	Pahang	
1:2	4.10	
2:3	4.26	4.81
3:4	3.86	
4:5	7.00	
	Jelai	
1:2	3.73	
2:3	3.4	3.36
3:4	3.33	
4:5	3.0	
	Tembeling	
1:2	4.24	
2:3	7.00	4.75
3:4	3.00	
	Semantan	
1:2	3.50	
2:3	4.67	3.72
3:4	3.00	
	Lower Pahang	
1:2	4.75	
2:3	4.00	5.25
3:4	7.00	
	Triang	
1:2	4.25	
2:3	2.67	3.31
3:4	3.00	
	Bera	
1:2	3.72	
2:3	5.5	3.74
3:4	2.0	

5. CONCLUSION

A comprehensive hydrological study requires the quantitative analysis of morphometric characteristics to fully understand drainage systems. This study used GIS-based evaluation to analyze the morphometric parameters of the Pahang River Basin and its six sub-basins, providing valuable insights into the basin's morphology and hydrological behavior.

The morphometric assessment revealed that the Jelai, Lower Pahang, and Tembeling basins are significant contributors to runoff in the downstream Pahang River. These sub-basins, characterized by their larger size and extensive stream networks, exhibit dendritic drainage patterns with stream orders reaching up to the fourth and fifth levels. Notably, the Pahang River Basin itself has a total stream length of 5,710,468 m across 626 streams, indicating a well-developed drainage network. The Lower Pahang sub-basin has the highest stream frequency and drainage density, which is corroborated by its 169 streams with a total length of 1,562,868 m.

The bifurcation ratios across the sub-basins were found to be moderate, with the Lower Pahang exhibiting a mean bifurcation factor of 5.25, the highest among all sub-basins. This suggests a relatively stable geological structure with moderate influence from structural controls. The Tembeling sub-basin also showed a high mean bifurcation factor of 4.75, which, along with its 114 streams totaling 1,063,807.80 m in length, highlights its significant contribution to downstream runoff.

The ongoing erosion and deposition processes observed along the meandering sections of the Pahang River are reshaping the river's course, particularly in areas where the river's gradient decreases, leading to increased sediment deposition. Across all basins, the bifurcation ratios suggest a balanced distribution of tributaries, indicative of moderate geological disturbance and a relatively stable landscape.

These findings emphasize the importance of morphometric studies in guiding effective catchment management plans. The insights into stream network patterns, basin shape, and erosion processes are crucial for predicting hydrological responses and planning sustainable land use.

Future research should delve deeper into the spatial and relief aspects of the Pahang River basin, focusing on how these factors interact with textural, material, and permeability characteristics to further enhance our understanding of the basin's hydrological dynamics. Additionally, incorporating field-based qualitative assessments could provide more context to the quantitative findings, offering a more holistic view of the basin's behavior and informing better management strategies.

6. REFERENCES

[1] J. I. Clarke, “Morphometry from maps,” in Essays in geomorphology, In G. H. Dury (Ed.), Ed., New : Elsevier Publishing Company, 1966, pp. 235–274.

[2] J. A. Prieto-Amparán et al., “A multivariate geomorphometric approach to prioritize erosion-prone watersheds,” Sustainability (Switzerland), vol. 11, no. 18, Sep. 2019, doi: 10.3390/su11185140.

[3] P. Sajadi, A. Singh, S. Mukherjee, Y. F. Sang, K. Chapi, and M. Salari, “Drainage network extraction and morphometric analysis in an Iranian basin using integrating factor analysis and geospatial techniques,” Geocarto Int, vol. 37, no. 3, pp. 896–925, 2022, doi: 10.1080/10106049.2020.1750060.

[4] N. Devi Miniandi and M. Sofiyan Sulaiman, “Morphometric analysis of the main river systems at Ulu Muda Forest Reserve, Kedah, Peninsular Malaysia,” Malayan Nature Journal, vol. 73, no. 3, pp. 297–309, 2021, [Online]. https://www.researchgate.net/publication/355166563

[5] M. S. Sulaiman, S. K. Sinnakaudan, N. N. Azhari, and R. Z. Abidin, “Behavioral of sediment transport at lowland and mountainous rivers: a special reference to selected Malaysian rivers,” Environ Earth Sci, vol. 76, no. 7, Apr. 2017, doi: 10.1007/s12665-017-6620-y.

[6] S. K. Jenson, “Applications Of Hydrologic Information Automatically Extracted From Digital Elevation Models,” 1991.

[7] S. A. Romshoo, S. A. Bhat, and I. Rashid, “Geoinformatics for assessing the morphometric control on hydrological response at watershed scale in the Upper Indus Basin,” J. Earth Syst. Sci., vol. 121, no. 3, pp. 659–686, 2012.

[8] A. N. Strahler, “Quantitative Analysis of Watershed Geomorphology,” American Geophysical Union, vol. 38, no. 6, Dec. 1957.

[9] R. E. Horton, “Erosional development of streams and their drainage basins; Hydrophysical approach to quantitative morphology,” Bulletin of the Geological Society of America, vol. 56, no. 3, pp. 275–370, 1945, doi: 10.1130/0016-7606(1945)562.0.CO;2.

[10] L. Leopold, M. Gordon Wolman P H Y S I O, S. L. Udall, and T. B. Nolan, “River Channel Patterns: B Aided, Meandering, And Straight,” Washington, 1963.

[11] S. A. Schumm, “Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey,” Bulletin of the Geological Society of America, vol. 67, no. 5, pp. 597–646, 1956, doi: 10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2.

[12] Pan Ia Lun, M. Barzani Gasim, M. Ekhwan Toriman, S. Abd Rahim, and K. Amri Kamaruddin, “Hydrological Pattern Of Pahang River Basin And Their Relation To Flood Historical Event,” Jurnal e Bangi, vol. 6, no. 1, pp. 29–37, 2011.

[13] NWRS, “Review of the National Water Resources Study (2000-2050) and Formulation of National Water Resources Policy,” Kuala Lumpur, 2011.

[14] M. K. A. Kamarudin, M. E. Toriman, N. A. Wahab, H. Rosli, F. M. Ata, and M. N. M. Faudzi, “Sedimentation study on upstream reach of selected rivers in Pahang River Basin, Malaysia,” Int J Adv Sci Eng Inf Technol, vol. 7, no. 1, pp. 35–41, 2017, doi: 10.18517/ijaseit.7.1.971.

[15] M. B. Gasim and M. I. Toriman, “Hydrological Pattern Of Pahang River Basin And Their Relation To Flood Historical Event,” 2011. [Online]. https://www.researchgate.net/publication/245584407

[16] W. T. Ashenafi, “Watershed Processing and Spatial Rainfall Analysis Ashenafi Wondimu Tekolla,” Lund University, Sweden, 2010. [Online]. Available: http://www.tvrl.lth.se

[17] C. Cruz, T. R. Ong, and M. H. Peralta, “Service area determination of fire stations in an urban setting through a GIS-based multi-criteria analysis: the case of Quezon City, Philippines,” in International Exchange and Innovation Conference on Engineering and Sciences, Kyushu University, 2022, pp. 412–418. doi: 10.5109/5909126.

[18] E. Ekren, “Investigation of Land Cover Change in Kahramanmaras Province (Turkey),” in International Exchange and Innovation Conference on Engineering and Sciences, Kyushu University, 2022, pp. 407–411. doi: 10.5109/5909125.

[19] A. Thankachan and N. Sahoo, “Determination of Morphological Parameters of a Watershed Using Remote Sensing and GIS,” International Journal of Advances in Engineering and Management (IJAEM, vol. 2, p. 625, 2008, doi: 10.35629/5252-0204625631.

[20] D. G. Tarboton, R. L. Bras, and I. M. Rodriguez-Iturbet Ralph, “On The Extraction Of Channel Networks From Digital Elevation Data,” 1991.

[21] J. E. Costa, “Hydraulics And Basin Morphometry Of The Largest Flash Floods In The Conterminous United States,” 1987.

[22] F. Altaf, G. Meraj, and S. A. Romshoo, “Morphometric Analysis to Infer Hydrological Behaviour of Lidder Watershed, Western Himalaya, India,” Geography Journal, vol. 2013, pp. 1–14, Apr. 2013, doi: 10.1155/2013/178021.

[23] O. Singh and A. Sarangi, “Hypsometric analysis of the lesser Himalayan watersheds using geographical information system,” Journal of Soil Conservation, vol. 36, no. 3, pp. 148–154, 2008, [Online]. Available: https://www.researchgate.net/publication/276986884