Understanding Geomorphological Dynamic of the Pahang River Basin and Its Sub Basin by Assessing Hypsometric Analysis

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/10.5109/7323330

出版情報：Proceedings of International Exchange and Innovation Conference on Engineering & Sciences (IEICES). 10, pp.647-652, 2024-10-17. International Exchange and Innovation Conference on Engineering & Sciences
バージョン：

Understanding Geomorphological Dynamic of the Pahang River Basin and Its Sub Basin by Assessing Hypsometric Analysis

Mohd Aliff Mohd Anuar[1,3], Mohd Shalahuddin Mohd Adnan[1], Mohamad Hafiz Hassan[2], Mohd Sofiyan Sulaiman[4], Lee Wei Koon[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 performs a hypsometric analysis of the Pahang River Basin and its sub basins to assess geomorphological and hydrological characteristics. Utilizing 30-metre resolution of Interferometric Synthetic Aperture Radar (IFSAR), the Digital Elevation Models (DEMs), we generated hypsometric curves and calculated integrals, revealing significant landscape variations. The basin primarily exhibits a mature landscape with concave curves, indicating balanced erosion and deposition, while some sub basins show convex curves, suggesting youthful topography and active erosion. These findings highlight spatial variability in hydrological processes, impacting runoff generation and sediment transport. Understanding these hypsometric properties is crucial for effective water resource management and supports targeted conservation strategies to mitigate erosion and enhance watershed stability*.

Keywords: Hypsometric Analysis, Basin, Geologic Stage

1. INTRODUCTION

Hypsometric analysis, which examines the relationship between horizontal cross-sectional drainage basin area and elevation, serves as a crucial tool in understanding watershed conditions. Often termed the drainage basin relief graph, the hypsometric curve, along with the hypsometric integral, provides significant insights into the overall slope and form of a drainage basin[1] This analysis relates to the volume of soil mass within a basin and the extent of erosion that has occurred compared to the remaining mass [2]. It functions as a continuous, non-dimensional distribution of relative basin elevations against the relative area of the drainage basin [3]

Comparative studies of hypsometric curves across different drainage basins under similar hydrologic conditions can reveal historical soil movement within those basins. The shape of the hypsometric curve can thus elucidate temporal changes in the original basin slope.[4] classified basins based on hypsometric curve shapes into young (convex upward curves), mature (S-shaped curves concave upwards at high elevations and convex downwards at low elevations), and peneplain or distorted (concave upward curves) stages. The shape of the hypsometric curve varies frequently during the early geomorphic development stages and stabilizes once the watershed reaches maturity.

Hypsometric analysis helps ascertain watershed susceptibility to erosion and prioritize areas for treatment. The slope of the hypsometric curve changes with watershed development stages, significantly influencing erosion characteristics and indicating the erosion cycle. The hypsometric integral (*HI*) also reflects the 'cycle of erosion,' the time required for land area reduction to base level [4] [5] This cycle includes three stages: manadnock (old) (*HI*=0.3), indicating a fully stabilized watershed; equilibrium or mature stage (*HI*=0.3 to 0.6); and inequilibrium or young stage (*HI*>0.6), indicating a watershed highly susceptible to erosion [4]

The integration of Geographic Information Systems (GIS) has enhanced the efficiency and accuracy of hypsometric analysis, allowing for detailed assessments of erosional topography [6], [7] Despite its importance, hypsometric analysis remains underutilized in watershed health studies, primarily due to the tedious data acquisition and analysis process. Utilizing GIS techniques in the hypsometric analysis of digitized contour maps significantly improves result accuracy and saves time.

In this study, we conduct a hypsometric analysis of the Pahang River Basin and its sub basins in Pahang state, Peninsula Malaysia. By examining the hypsometric characteristics of this region, we aim to provide insights into the geomorphological and hydrological processes influencing the basin, aiding in effective watershed management and conservation strategies columns.

2. STUDY AREA

The Pahang River Basin is located in Pahang state, the largest state in Peninsula Malaysia (Fig. 1). The geographic coordinates of this basin are between 101° 30' E - 103° 30' E longitude and 3° 00' N - 4° 45' N latitude. The basin covers a total catchment area of 28,682 km². The primary highland areas within the basin include the Titiwangsa Range on the western side, the Tahan Range in the central north, and the East Coast Range in the northeast. These upland regions are highly dissected and generally range from 1,000 m to 2,180 m in elevation[8] [9].

The basin's topography varies significantly, with the upper catchment characterized by steep slopes, while the lower catchment is predominantly flat and swampy. The Pahang River, the main river in the basin, flows for 459 km, making it the longest river in Peninsula Malaysia. The river begins at the confluence of the Jelai and Tembeling rivers in the Titiwangsa Mountains and drains into the South China Sea. [10], [11]

The climate of the Pahang River Basin is generally hot and wet, with significant rainfall occurring during the northeast monsoon period, which contributes to almost 40 percent of the annual total rainfall Annual rainfall in the basin ranges from 1609 mm in Temerloh to 2132.36 mm in Lubuk Paku. The highest rainfall typically occurs from November to March, influenced by the northeast monsoon.[8], [12], [13]

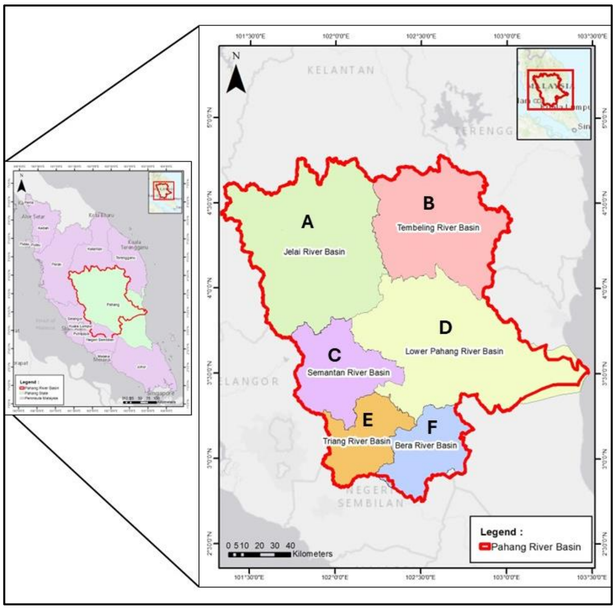

Fig. 1. Pahang River Basin Study Area

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

3.1 Data Acquisition and Processing

In this study, high-resolution Digital Elevation Models (DEMs) were generated using raster data with 30-meter resolution Interferometric Synthetic Aperture Radar (IFSAR). The IFSAR-DEM was utilized to delineate the Pahang River Basin and its sub basins using the hydrology tools in the Spatial Analyst extension of ArcGIS 10.5.1. The drainage network ordering was adopted from Strahler's stream ordering scheme [14]. The IFSAR-DEM was cropped based on the generated sub basins for slope classification.

3.2 Hypsometric Analysis

Hypsometric analysis aims to develop a relationship between the horizontal cross-sectional area of the watershed and its elevation. For this study, the hypsometric analysis of the Pahang River Basin was conducted using GIS approaches. The hypsometric curves were prepared following the method outlined by [4]. The hypsometric curve was generated by plotting the relative elevation (*h/H*) on the ordinate against the relative area (*a/A*) on the abscissa. The relative area is calculated as the ratio of the area above a particular contour (*a*) to the total area of the sub-watershed above the outlet (*A*). Similarly, the relative elevation is obtained as the ratio of the height of a given contour (*h*) from the base plane to the maximum basin elevation (*H*)b[15]. The resulting hypsometric curves provide details of the volume of landmass present above or below the reference basal plane [16]

3.3 Estimation of Hypsometric Integral (HI)

The Hypsometric Integral (*HI*) is generally calculated from the hypsometric curve, as demonstrated by [17]. The hypsometric integral is proportional to the ratio of the area under the curve to the area of the entire square formed by enclosing it. It is expressed as a percentage, obtained from the percentage hypsometric curve by measuring the area under the curve. The elevation-relief ratio (E) used to calculate the *HI* is defined as follows:

$$E(HI) = \frac{Elev_{mean} - Elev_{min}}{Elev_{max} - Elev_{min}}$$

where $Elev_{mean}$ is the weighted mean elevation of the delineated watershed, and $Elev_{min}$ and $Elev_{max}$ are the minimum and maximum elevations within the watershed, respectively.

Based on the hypsometric integral (*HI*), the stage of watershed development is determined using the threshold limits recommended by [18]

i. Basin at youthful stage : $HI \geq 0.6$
ii. Basin at equilibrium stage : $0.35 \leq HI < 0.6$
iii. Basin at mature (old) stage: $HI < 0.35$

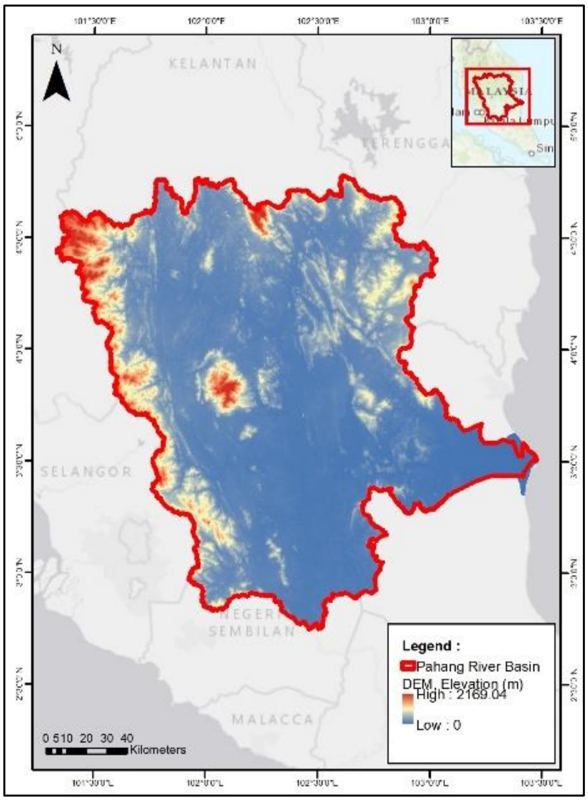

Fig. 2. Pahang River Basin DEM

Table 2. Basin 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	21.0	768.0

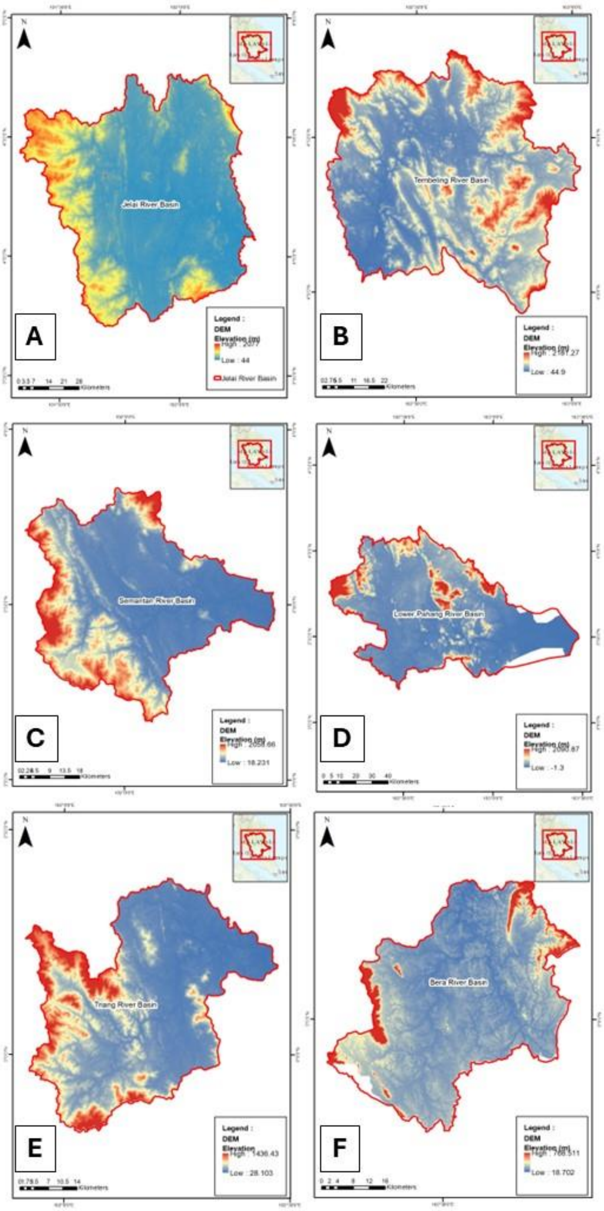

Fig. 3. Sub Basin DEM

4. RESULTS AND DISCUSSION

The hypsometric curve (*HC*) for the Pahang River Basin, and its sub basin as illustrated, provides a graphical representation of the distribution of elevations within the basin. The hypsometric curves for the river basins in the Pahang River Basin predominantly exhibit a concave shape, indicating they are in an equilibrium or mature stage. This concavity suggests significant past erosion and sediment transport, with most areas now situated at lower elevations.

For the Pahang River Basin, the curve's steep initial slope shows a large portion of the basin at lower elevations, As the curve approaches the upper right corner (relative area near 1.0), the slope becomes much gentler. This indicates that a smaller portion of the basin area is at higher elevations, corresponding to the steep, upland regions of the basin. With the *HI* values of 0.47 to 0.48 confirming its equilibrium state.

Similarly, the Jelai River Basin's concave curve indicates extensive past erosion, resulting in most of its area being at lower elevations. The *HI* value of 0.48 suggests the concave shape signifies extensive past erosion, leading to sediment deposition in lower areas. The basin's equilibrium stage implies a balance between erosional and depositional processes, indicating stability in the geomorphic cycle.

The Tembeling River Basin's curve has a pronounced initial steep drop, showing extensive erosion with most areas at lower elevations. Its *HI* value of 0.48 also indicates an equilibrium stage, suggesting a mature and stable landscape. The curve's shape suggests extensive erosion has occurred, resulting in most of the area being at lower elevations. The equilibrium stage indicates a mature landscape where erosion and sediment deposition are balanced.

This stability is crucial for watershed management, as it suggests that major erosional events are less likely to occur without significant external changes. The Semantan River Basin's curve displays a relatively steep initial rise, indicating significant areas at lower elevations due to extensive erosion. An *HI* value of 0.47 places this basin in an equilibrium stage, suggesting a mature, stable watershed where erosion continues to shape the landscape.

The Lower Pahang River Basin's curve for the Lower Pahang River Basin is concave with a sharp initial drop, indicating most of the area is at lower elevations. The *HI* value of 0.47 places this sub-basin in the equilibrium stage, the sharp initial drop suggests a highly eroded landscape where material has been transported to lower elevations. The equilibrium stage indicates that this sub-basin has reached a stable form, with erosion and deposition processes balanced.

For the Triang River Basin, curve is also concave but slightly steeper in the initial section, indicating a considerable amount of the area is at mid to lower. The *HI* value of 0.47 suggests a stable, mature landscape The shape and *HI* value suggest that the Triang River Basin is stable, with ongoing erosion shaping the landscape. The basin's morphology indicates it is well into the geomorphic cycle, where deposition and erosion are balanced.

Lastly, the Bera River Basin's curve has a steep initial drop that gradually flattens towards lower elevations, The steep initial drop in the curve indicates that a significant portion of the basin area is at lower elevations, suggesting substantial past erosion. The equilibrium stage signifies that the basin has reached a mature state where erosion and deposition processes are balanced.

This implies a stable landscape with a low likelihood of drastic geomorphic changes in the near future. With an *HI* value of 0.48, the basin is in an equilibrium stage, signifying a mature state with balanced erosion and deposition processes, implying a stable landscape with a low likelihood of drastic geomorphic changes.

The hypsometric curves of these sub-basins within the Pahang River Basin share similar characteristics, with all indicating an equilibrium stage of development. This stage is marked by significant past erosion and a mature landscape where sediment transport processes have led to a stable geomorphic structure.

The concave shapes of the curves reflect the extensive erosion that has occurred, resulting in lower elevations dominating the basin areas. DEMs are susceptible to errors arising from various sources such as data collection methods, interpolation techniques, and the quality of the original data.

Any inaccuracies in the DEM can lead to erroneous representations of the terrain, which in turn can affect the hypsometric curve and the overall interpretation of the watershed's geomorphology. Higher resolution DEMs provide more detailed and precise representations of the terrain, capturing finer topographic features that lower resolution DEMs might miss.[19] [20]
In contrast, lower resolution DEMs can smooth out critical terrain features, leading to less accurate hypsometric curves. This can result in an underestimation or overestimation of the watershed's erosional stage and its geomorphic characteristics.

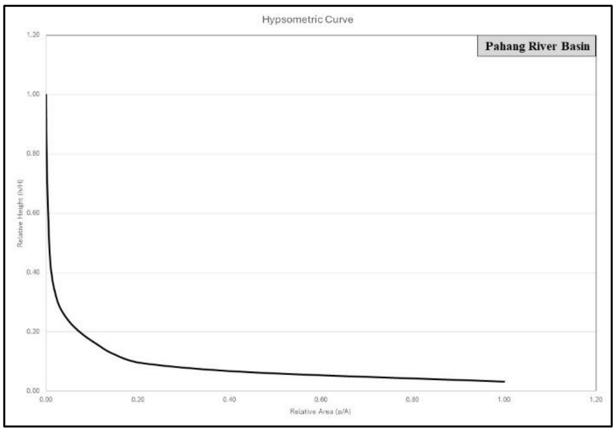

Fig. 4. *HC* for Pahang River Basin

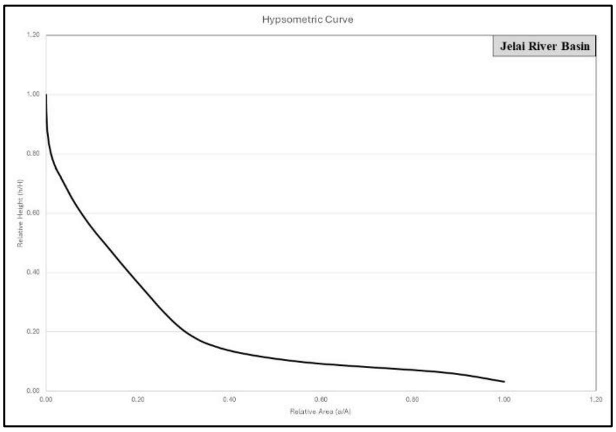

Fig. 5. *HC* for Jelai River Basin

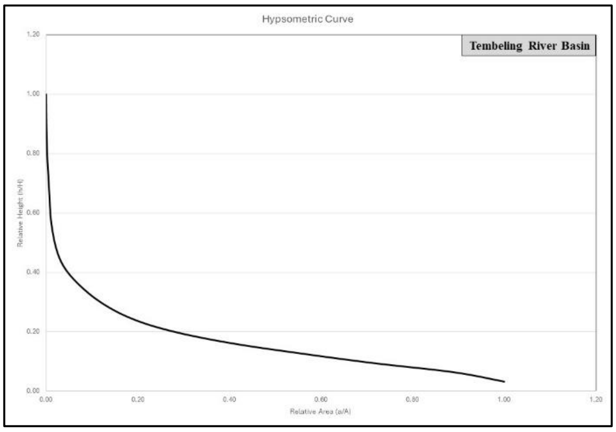

Fig. 6. *HC* for Tembeling River Basin

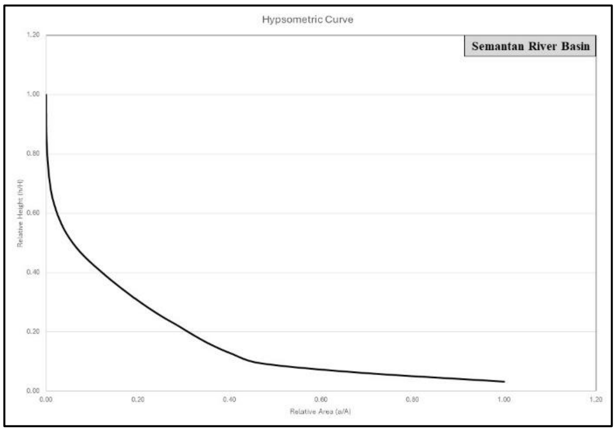

Fig. 7. *HC* for Semantan River Basin

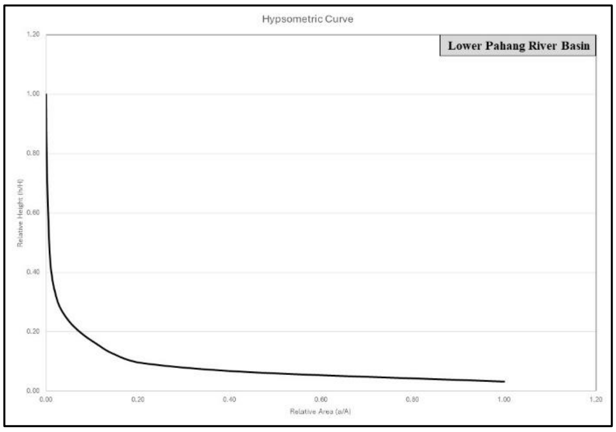

Fig. 8. *HC* for Lower Pahang River Basin

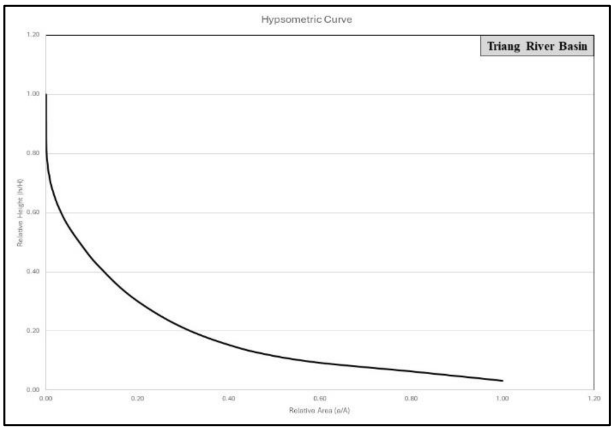

Fig. 9. *HC* for Triang River Basin

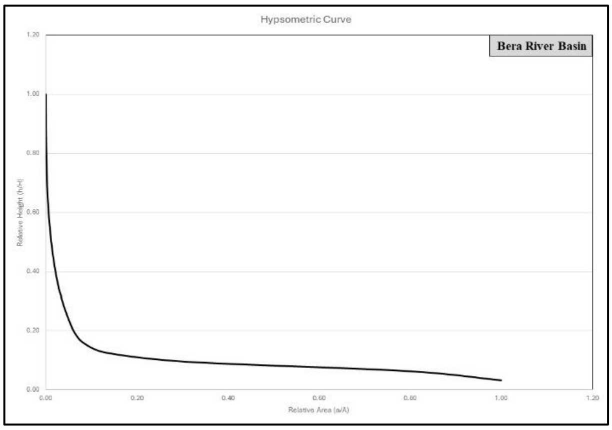

Fig. 10. *HC* for Bera River Basin

The hypsometric analysis for the Pahang River Basin and its sub basins reveals important insights into the geomorphological and hydrological conditions of the region. The calculated hypsometric integral (*HI*) values and corresponding geological stages for the sub basins are summarized in the table below:

Table 3. Hypsometric Integral (*HI*)

River Basin	Area (km^2)	Hypsometric Integral HI	Geological Stage
Pahang Main	28680.2865	0.47	Equilibrium
Jelai	8145.09	0.48	Equilibrium
Tembeling	5337.62	0.48	Equilibrium
Semantan	2885.742	0.47	Equilibrium
Lower Pahang	8053.67	0.47	Equilibrium
Triang	2053.37	0.47	Equilibrium
Bera	2160.09	0.48	Equilibrium

The hypsometric integral (*HI*) values for the Pahang River Basin and its sub basins range from 0.47 to 0.48, indicating that all the sub basins are in the equilibrium stage of geological development. According to Miller (1953), sub basins with *HI* values between 0.35 and 0.6 are considered to be in the equilibrium stage. This stage is characterized by a balanced state where erosion and deposition processes are relatively stable. The study from [21] stated the HI value for Ulu Keliu in Malaysia is 0.35 fall in the equilibrium stage.

The equilibrium stage of the sub-basins within the Pahang River Basin suggests a moderate susceptibility to erosion. Unlike youthful basins ($HI > 0.6$), which are highly prone to erosion, or mature basins ($HI < 0.35$), which are more stable and less prone to erosion, equilibrium basins maintain a balance between erosion and sediment deposition. This balance indicates that the Pahang River Basin and its sub-basins are neither highly erodible nor completely stable, necessitating moderate management efforts to maintain watershed health.

Understanding the *HI* values and the corresponding geological stages is crucial for effective watershed management and conservation strategies. Since the Pahang River Basin and its sub-basins are in the equilibrium stage, management practices should focus on maintaining this balance by preventing excessive erosion and promoting sustainable land use practices. Measures such as reforestation, controlled agricultural practices, and the implementation of erosion control structures can help preserve the current state of the basin.

The slight variations in *HI* values among the sub basins, although all within the equilibrium range, can provide further insights into localized conditions and processes. For example, sub basins with an *HI* of 0.48 (Bera, Jelai, Tembeling) might be at a slightly different point in the equilibrium stage compared to those with an *HI* of 0.47 (Lower Pahang, Pahang Main, Semantan, Triang). These differences, albeit small, might indicate varying degrees of stability and erosion potential within the equilibrium stage.

5. CONCLUSION

The hypsometric curve for the Pahang River Basin illustrates the distribution of elevations within the basin, indicating that it is in an equilibrium stage with significant areas at lower elevations due to past erosion and deposition processes. This information is crucial for understanding the geomorphological characteristics of the basin and for planning effective watershed management strategies to maintain its health and stability The hypsometric analysis of the Jelai, Tembeling, Semantan, Lower Pahang, Triang, and Bera sub-basins reveals that these regions are in an equilibrium stage of geomorphic development, characterized by significant erosion and stable landscapes. This information is essential for developing targeted watershed management strategies to sustain the health and stability of these basins.

The hypsometric analysis of the Pahang River Basin and its sub basins demonstrates that the region is predominantly in an equilibrium stage, with moderate susceptibility to erosion. This understanding aids in developing targeted watershed management strategies to maintain the balance between erosion and deposition, ensuring sustainable land and water resource management in the basin.

ACKNOWLEDGEMENTS

The authors express gratitude to Research Management Centre (RMC) UTHM for awarded Post Graduate Research Grant Vot. No. H352. Universiti Tun Hussein OnnMalaysia for the facility and Ministry of Higher Education Malaysia

6. REFERENCES

[1] J. A. Krug, W. E. Wrather, and W. B. Langbein, "Topographic Characteristics Of Drainage Basins," Washington, 1947.

[2] J. E. Hurtrez, F. Lucazeau, J. Lavé, and J. P. Avouac, "Investigation of the relationships between basin morphology, tectonic uplift, and denudation from the study of an active fold belt in the Siwalik Hills, central Nepal," J Geophys Res Solid Earth, vol. 104, no. B6, pp. 12779–12796, Jun. 1999, doi: 10.1029/1998jb900098.

[3] A. N. Strahler, "Quantitative Analysis of Watershed Geomorphology," American Geophysical Unior, vol. 38, no. 6, 1957.

[4] A. N. Strahler, "Dynamic basis of geomorphology," Bulletin of the Geological Society of America, vol. 63, no. 9, pp. 923–938, 1952, doi: 10.1130/0016-7606(1952)63[923:DBOG]2.0.CO;2.

[5] G. Sarp, V. Toprak, and S. Duzgun, "Hypsometric Properties Of The Hydrolic Basins Located On Western Part Of Nafz".

[6] Ashish. Pandey and V. M. Chowdary, "Morphological analysis and watershed management using geographic information system," Hydrology, vol. 27, no. 3 & 4, pp. 71–84, 2004.

[7] 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

[8] NWRS, "Review of the National Water Resources Study (2000-2050) and Formulation

of National Water Resources Policy," Kuala Lumpur, 2011.
[9] 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.
[10] M. K. A. Kamarudin et al., "Hydrological and climate impacts on river characteristics of pahang river basin, Malaysia," Heliyon, vol. 9, no. 11, Nov. 2023, doi: 10.1016/j.heliyon.2023.e21573.
[11] 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.
[12] W. T. Ashenafi, "Watershed Processing and Spatial Rainfall Analysis Ashenafi Wondimu Tekolla," Lund University, Sweden, 2010. [Online]. Available: http://www.tvrl.lth.se
[13] M. B. Gasim and M. I. Toriman, "Hydrological Pattern Of Pahang River Basin And Their Relation To Flood Historical Event," 2011. [Online]. Available: https://www.researchgate.net/publication/245584407
[14] A. N. Strahler, Quantitative geomorphology of drainage basin and channel networks. New York: McGraw-Hill Book Company, 1964.
[15] D. F. Ritter, Process Geomorphology. New York: McGraw-Hill, 1995. [Online]. Available: https://people.wou.edu/~taylors/geog522/rittchp5.pdf
[16] V. J. Markose and K. S. Jayappa, "Hypsometric analysis of Kali River Basin, Karnataka, India, using geographic information system," Geocarto Int, vol. 26, no. 7, pp. 553–568, Nov. 2011, doi: 10.1080/10106049.2011.608438.
[17] R. J. Pike and S. E. Wilson, "Elevation-Relief Ratio, Hypsometric Integral, and Geomorphic Area-Altitude Analysis," Geological Society of America, vol. 82, pp. 1079–1084, 1971.
[18] T. V By C MILLER, "REVIEWS A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area," 2016. [Online]. Available: http://www.journals.uchicago.edu/t-and-c
[19] 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.
[20] 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.
[21] J. A. Vanderwaal and H. Ssegane, "Do Polynomials Adequately Describe the Hypsometry of Monadnock Phase Watersheds?," J Am Water Resour Assoc, vol. 49, no. 6, pp. 1485–1495, 2013, doi: 10.1111/jawr.12089.