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Development of stream classification system on tropical areas with statistical approval in Pahang River basin, Malaysia

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ABSTRACT

Stream classification system identified the characteristic of stream on the basin. Stream behaviors can provide guidance for future problem in this basin. This study discusses on the development of stream classification system on tropical areas with statistical approval based on remote sensing, geographical information system, and river hydrographic survey based on Rosgen classification system. Pahang River Basin is the longest river in Peninsular Malaysia and the main channel to drain off water from the inundated area of Pahang Basin to the South China Sea. The environmental statistical techniques were used to identify the clustering development on the tropical river system using hierarchical agglomerative cluster analysis (HACA), discriminant analysis (DA) and principal component analysis (PCA). The HACA results indicated that the main of Pahang tropical river system is classed into three main clusters namely the upstream reach, middle stream reach and downstream reach. The calibration and validation analyses proved the DA with 100% confident level. The PCA indicates three variables demonstrated significant correlations that are domination slope R^2 = 0.796, bankfull width-to-depth ratio R^2 = −0868, and sinuosity R^2 = 0.557, respectively. Model of stream classification system with future geomorphology process and problem expectations is produced where the first class considered in terrace and valley erosion zone, second class in a low terrace of land near the channels and sediment transports zone, and third class in valley deposition and floodplain zone. The results are important to local authorities as a decision support system using the river clustering model for Pahang River Basin.

Keywords: Stream classification system; Tropical areas; Pahang River Basin; Rosgen classification system; HACA

1. Introduction

Stream or river classification system is very important to identify the characteristic of stream on the river basin. Many classification approaches have been proposed for rivers and streams, serving a wide range of purposes, including scientific research, river management and river restoration and conservation [1–6]. To the untrained eye, streams and river systems may appear to be a simple network of natural open channels. In reality, these networks are a complex system consisting

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of multiple parameters used to represent dimension, flow, sediment, etc. Stream classification is the process of trying to analyze these parameters and label them in a descriptive manner [7]. To date, there are many methods that are being used for river classification including methods developed by Strahler [8], Leopold and Wolman [9], Whiting and Bradley [10], and the common and arguably the most used method is the Rosgen method [11–13]. Strahler's method is one of the first methods developed in 1952 for stream classification. This method simply describes the order of streams. This method starts with the smallest tributaries that are considered as the first order. When two of these tributaries meet, the resulting tributary is considered as the second order. When two second-order streams meet, the result is the third order and so on [9]. Although this type of classification is fairly vague, it is an important indicator of stream size and drainage [14]. First- and second-order lengthy streams are often characterized as man-made or severely altered natural channels. Another early method is developed by Leopold and Wolman in 1952 describing streams as braided, meandering, or straight. Leopold and Wolman are particularly concerned with the plan view of the river system and describe channels as one of the three categories listed above. The method looks at specific reaches of the system as opposed to the whole system due to the river system is often changing from straight, to meandering, to braided, etc. This early method was developed in order to attempt to "understand the mechanisms by which these laws operate in a river." [9].

Whiting and Bradley [10] developed a stream classification system in 1993 that differed from the common techniques used. Another common classification technique focuses more on large river systems, whereas this technique was developed for headwater channels of small size. The variables considered in this process are hill slope gradient, channel gradient, valley bottom width, channel width, and sediment size. This technique uses a process-base approach based on the above parameters [10]. Other stream classification system that efficiently used in river classification is Rosgen classification system. For the purpose of easy stream classification system, Rosgen has broken up clearly the processes; listed out into four levels. The river starts by being classified using Level I. The river is then further classified into Level II, by describing the river in the next sub-genre of classification. The river is then further classified into Levels III and IV. Each level deals with a different topic of characterization. Level I begin with geomorphic characterization; Level II deals with morphological descriptions; Level III characterizes the streams state; and finally, Level IV addresses validation of process characteristics [15]. For the purpose of clarity, Rosgen primarily describes Levels I and II in detail, and only briefly describes Levels III and IV. In determining Rosgen stream types, three characteristics of the stream's appearance (entrenchment ratio, bankfull width-to-depth ratio [W/D ratio], and sinuosity) are used to divide channels into eight primary stream types denoted by the capital letters – A, B, C, D, DA, E, F, and G [15,16]. Therefore, this study will be focusing mainly on geomorphic characterization such as dominant slope range, entrenchment ratio, bankfull W/D ratio, and sinuosity.

River is the main water sources for the life of the world [17–19]. River is also crucial in the development of human civilization. According to Nasir [20], the development of Malay civilization mostly occurred near from the river banks. Even in Malaysia, the river plays an important role in the growth of a city. There is no doubt that most names of the city in Malaysia began with the "River" or "*Kuala*" words (*Kuala* means the downstream of the river), and most of these locations are situated near the confluence of the river. For this study, developments of stream classification system on tropical areas are focusing in Peninsular Malaysia to represent river in tropical areas. Pahang River is the longest river system in Peninsular Malaysia. The length of this river system thus reflects that it is a large basin area; therefore, various problems arose and faced by the Pahang River and surrounding communities can be the examples to represent the tropical areas in Peninsular Malaysia [19]. Other reasons why Pahang River has been chosen for investigation are the availability of good database and good maps covering the study areas for stream classification system study.

Most studies discuss about the changes of climate condition especially rainfall intensity level and analyze the impact on the water resources. This study showed the climate condition that reflects to the stream classification system in tropical areas. Pahang River Basin has high density of rainfall level every year. The range of annual rainfall intensity in Pahang River Basin is estimated to range about 1,750–3,250 mm (Figs. 1–3), where most of the occurred during the Northeast Monsoon is between mid-October until mid-January on the East Coast of Peninsular Malaysia. The high rainfall intensity in upstream areas caused the high flow level and causing floods phenomenon and at the same time effected on the evolution of the meander of the river. There are three stations of rainfall intensity from DID (Jabatan Pengairan dan Saliran Malaysia), which are located along the main stream of Sungai Pahang; Yap River (JPS Station: 4023001), Temerloh (JPS Station: 3424081), and Lubuk Paku (JPS Station: 3527092). These stations were selected to represent the estimated rainfall data will give the impact of changes in the evolution of the river slowly along the main stream of the river. Fig. 1 showed the distribution of rainfall intensity at Yap River Station from 1980 until 2012, the highest level in February 1981 which 659 mm, followed by 538 mm in October 1981, 416 mm in October 1984, 432 mm, 557 mm and 406 mm in October, November and December 1986, respectively, 458.5 mm in 1988 and 445.5 mm in 1993. Fig. 2 showed the distribution of rainfall intensity at Temerloh Station from 1980 until 2012, represents a sub-regional center of Pahang River Basin. Within 32 years, this trend proved the highest increasing of rainfall intensity along the Pahang River Basin, which is the main stream in this study. Temerloh is one of the active urbanization areas from year to year which caused localized heating and affected the trend of rainfall intensity. Fig. 3 showed the distribution of rainfall intensity at Lubuk Paku Station from 1980 until 2012, this trend proved the second highest along the main flow of the Pahang River Basin. The intensity recorded 963 mm in December 2007, 410 mm on 1985, 520 mm in 1987, 501 mm in 1988, 511 mm in 1989, 475.5 mm in 1990, 546 mm in 1991, 431.5 mm in 1993, 655 mm in 1994, 504.5 mm in 1998, 559 mm in 2001, 444.5 mm in October 2007 and 438.5 mm in 2009.

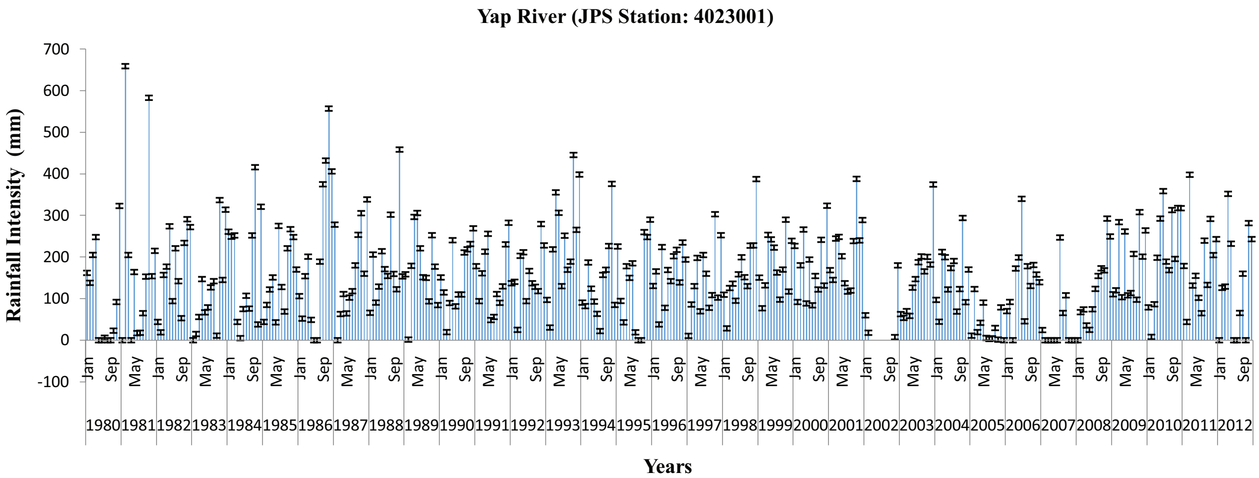


Fig. 1. The distribution of rainfall intensity at Yap River Station, 1980–2012.

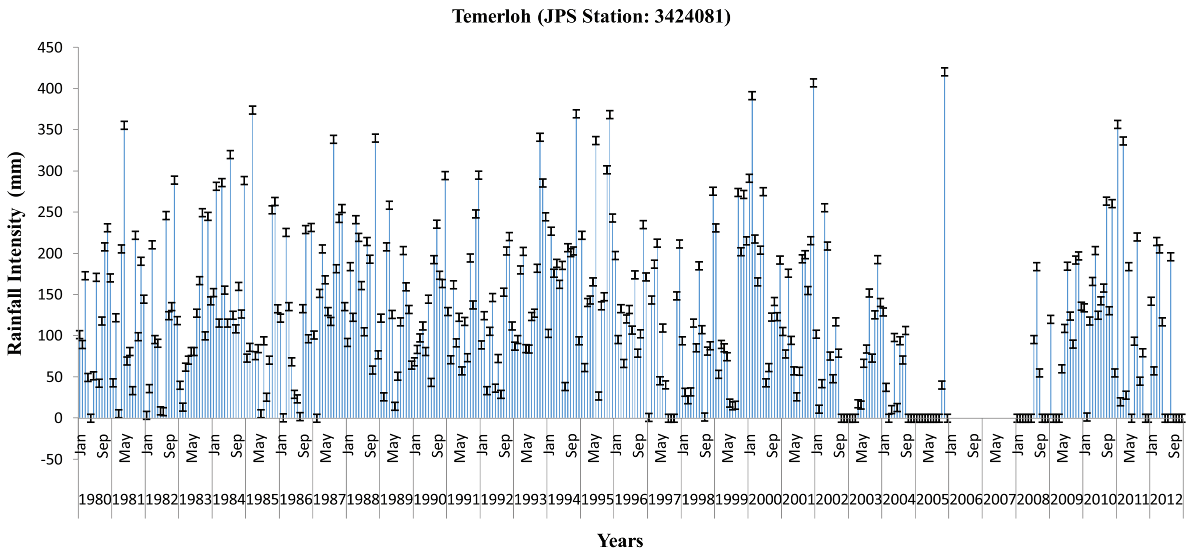


Fig. 2. The distribution of rainfall intensity at Temerloh Station, 1980–2012.

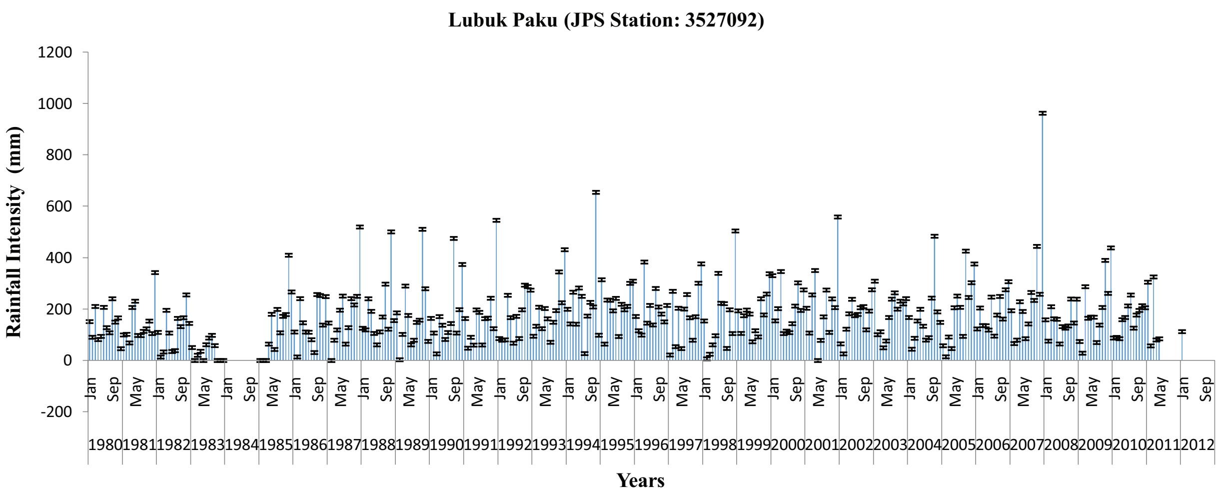


Fig. 3. The distribution of rainfall intensity at Lubuk Paku Station, 1980–2012.

2. Materials and methods

2.1. Study area

Pahang River is the longest river in Peninsular Malaysia with 459 km in length and the upstream is located at the main range of Titiwangsa Range (Banjaran Titiwangsa). Pahang River, which is located at Pahang River Basin, is the main channel responsible to drain the water from this basin to South China Sea [20,21]. Pahang River is divided into Tembeling and Jelai Rivers and both rivers meet at Kuala Tembeling (Fig. 4), which is located 300 km away from the estuary of Pahang River (Kuala Pahang). The river meanders through townships such as Jerantut, Temerloh, Maran, Bera, Pekan and finally flows into the South China Sea, which located on the East Coast of Peninsular Malaysia [22,23].

The main focus of this study is to develop river classification system on tropical areas with statistical approval method. Therefore, the main river data in Pahang River will be used to investigate and develop stream classification system in this river. To facilitate the study, the main Pahang River has been divided into 1–29 sub-plots, by ±10 km^2 range in the main river as demonstrated in Fig. 4. In the Pahang River, Malaysia, the river distribution or name is very much unclear. For example, in upstream of the Pahang River at Tahan, the local people call it "Kuala Tembeling" or downstream of the river. However, Kuala Tembeling is located at the upstream of Pahang River. Therefore, this study will also classify the upstream, middle stream and downstream of this river. The classification is also very critical to local authorities to make decision according to the cluster or guidelines for future study of Pahang River, Malaysia, specifically and for tropical river generally.

2.2. Methods

In this study, there are few variables, which become priority, to be used for stream classification system based on

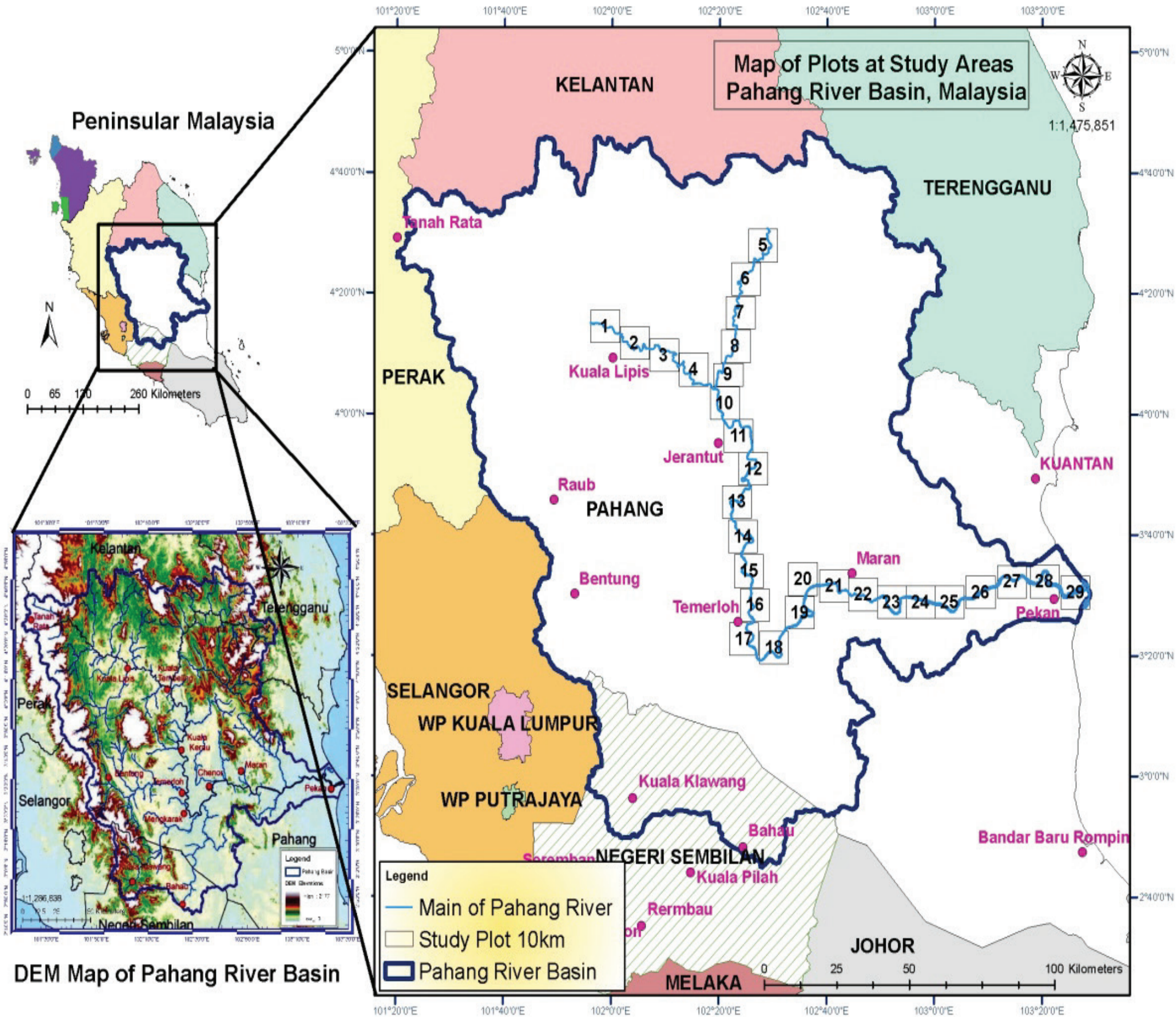


Fig. 4. Location of plots at Pahang River, Malaysia (DEM map of Pahang River Basin refer as the elevation distribution of study area – lowest 0 m from MSL, highest 2177 m from MSL).

Rosgen classification system. The selected variables to be considered in the analysis include dominant slope range, river cross-station, plan view, entrenchment ratio, bankfull W/D ratio, and sinuosity. The remote sensing and geographic information system (GIS) were used to identify and produce the main database for the whole Pahang River Basin. Radarsat-1 2010 Satellite Imagery from Malaysian Remote Sensing Agency and topographic maps from Department of Survey and Mapping Malaysia (JUPEM) has been processed to get the plan view, sinuosity analysis and mean sea level (MSL) topographic data. As for the ground data, river survey on each sub-plot has been done and this is very important to update and validate the data [24]. The calculation of each main criterion was carried out using the database following Eqs. (1)–(5):

$$\text{Dominant slope range } \left(\text{DSR}\right): \frac{\text{Elevation change}}{\text{Distance}} \tag{1}$$

$$\text{River cross} - \text{station } \left(\text{A}\right): \text{ Depth x Width } \left(\text{m}^2\right) \text{ or } \\ \text{A } = \text{ ½ Depth x Width } \left(\text{m}^2\right) \tag{2}$$

Plan view (PV): using GIS technique

$$\text{Entrenchment ratio}: \frac{\text{Flood Prone width}}{\text{Bank full Width}} \tag{3}$$

$$\text{Bank full width} - \text{to} - \text{depth ratio}: \frac{\text{Bank full Width}}{\text{Average Depth}} \tag{4}$$

$$\text{Sinuosity}: \frac{\text{Channel Length } \left(\text{L}\right)}{\text{Valley Length } \left(\text{Z}\right)} \tag{5}$$

2.3. Statistical analysis

Envarometric techniques such as hierarchical agglomerative cluster analysis (HACA), discriminant analysis (DA), and principal component analysis (PCA) are used to develop the stream classification system via river characteristic in the river basin. HACA was used to analyze and classify the river characteristic model based on the homogeneity class, while the application of these methods is able to unveil and identify the same characteristic and also the same problem in the river system according the main criteria in this classification. Calibration and validation model was done by DA in order to confirm the HACA model. After that, PCA studies will be able to demonstrate strong coefficient from the class in this study and, hence, to be able to know the most contributing variables in this model.

2.3.1. Hierarchical agglomerative cluster analysis

HACA indicates groupings of samples by linking inter-sample similarities and illustrates the overall similarities of variables in the data set [25]. HACA is one of the methods utilized to cluster all the observations into groups based on their similarities. The result of HACA is visualized by using a tree diagram, also known as dendrogram which vividly shows the procedure in a HACA procedure [26]. For this study, the HACA possesses functionality to cluster all the observations of the main criteria on the stream classification data into groups based on its homogeneity characteristic. The application of this method facilitated and expedited the process to identify a set of observations, which showed the homogeneity characteristic. Hence, this method is very practical and applicable in this study.

2.3.2. Discriminant analysis

DA is a method utilized to reclassify observations in a clustering group by categorizing them into their own classes, which is significantly easier to be located after being predicted during the cluster analysis process. DA is able to dimensionally form a large data set that is reduced into a few most effecting parameters, whereby it indicates a few significant parameters that are responsible for most of the variations in this study [27]. It also aids in interpreting a complex data for spatial and temporal variations. This method contains forward and backward stepwise modes and the comparisons are made of the response results, of which a higher percentage illustrates the most significant variables to be taken. Besides, it also depicts parameters that indicate the most significance for further analysis. The DA is calculated using Eq. (6):

$$f(G_i) = k_i + \sum_{j=1}^{n} W_{ij} P_{ij} \tag{6}$$

where i is the number of groups (G), k_i is the constant inherent to each group, n is the number of parameters used to classify a set of data into a given group, and w_j is the weight coefficient assigned by DF analysis (DFA) to a given parameter (P_j).

2.3.3. Principal component analysis

PCA is a technique concerning with the moldings of new variables after following a few processes and these new variables have a linear combination of the original variables. The amount of new variables produced from this analysis is the same amount as the original variables but totally there is no reciprocal relation to be compared with. PCA is used to reduce the dimensionality of the data set by explaining the correlation among a large set of variables in terms of a small number of underlying factors or principal components without losing much information [28–30]. It allows the assessment of associations between variables since they have indicated participation of individual chemicals in several influence factors [31]. PCA like any other multivariate statistical method is sensitive to outliers, missing data and poor linear correlation among variables due to poorly distributed variables [32].

This technique was employed in this study with two aims to be achieved, whereby the first one is to acquire data reduction, and the latter is to interpret the data. By adopting the technique, it is easier to identify a linear composite of new variables from its origin. This is important in calculating the variations among them in order to cluster those variables effectively. New variables are termed as principal component score (PCS), where the production of PCS is located due to the coordinates of the observation respectively for each of the axes. The new axes are referred as principal components (PCs) and PCS is a linear combination of the origin variables. The PC can be assessed as Eq. (7):

$$Z_{ij} = a_{i1}x_{1j} + a_{i2}x_{2j} + \ldots + a_{im}x_{mj} \quad (7)$$

where z is the component score, a is the component loading, x is the measured value of the variable, i is the component number, j is the sample number and m is the total number of variables [33].

To attain the maximum variation in the data, all new variables need to be calculated, while those that are not calculated in the first new variable need to go through the second calculation based on the new variables. Finally, for the new variables that have not been calculated yet in the first and second calculation, the third calculation is needed in order to get the maximum variance. These methods are called varimax rotation. All new calculated variables are non-reciprocal and are labeled as new variables taken from $p-1$ variables which have not been calculated for the maximum variance before.

For example, the research conducted by Chabukdhara and Nema [34] explained that the monitoring stations might have different water depth with several times by monitoring, where a lot of parameters involved during the water sampling process and the method itself are able to determine those variations based on temporal and spatial variations. Based on this evidence, the varimax rotation should be applied to produce a good data interpretation. The varimax rotation aimed to produce new groups of variables with eigenvalues more than 1 and it is considered as significant. The new variables are named as varimax factors (VFs). The fundamental model of this technique is stated as Eq. (8):

$$Z_{ij} = a_{f1}x_{1i} + a_{f2}x_{2i} + \ldots + a_{fm}f_{mi} + e_{fi} \quad (8)$$

where z is the measured value of a variable, a is the factor loading, f is the factor score, e is the residual term accounting for errors or other sources of variation, i is the sample number, j is the variable number, and m is the total number of factors. Overall, this method of study can be summarized as shown in the conceptual framework (Fig. 5).

3. Results and discussion

Based on river survey and data analysis study, Tables 1–6 show the Rosgen stream classification system results in Stations 1 –29 at main stream of Pahang River. From the results, the classification of main stream Pahang River based on homogeneity characteristic stream classification system was successfully performed by HACA. Fig. 6 shows the automatic classification on this analysis; separating all the data into three clusters.

Based on results in Fig. 6, 17 plots were classified as class 1, which include plots 4, 5, 1, 2, 3, 10, 8, 6, 18, 12, 13, 7, 22, 11, 14, 9, and 21 where mostly are in the upland areas. For the class 2, 6 plots were classified, which include plots 19, 20, 24, 15, 16, and 17. In class 3, 6 plots identified include plots 23, 28, 25, 29, 26, and 27 where most plots are in the lowland areas in the Pahang River Basin.

The results illustrated that the classification and identification of plots based on their similarities in rates of river classification characteristic became clearer and more distinct. In this analysis, the HACA has affirmed that its

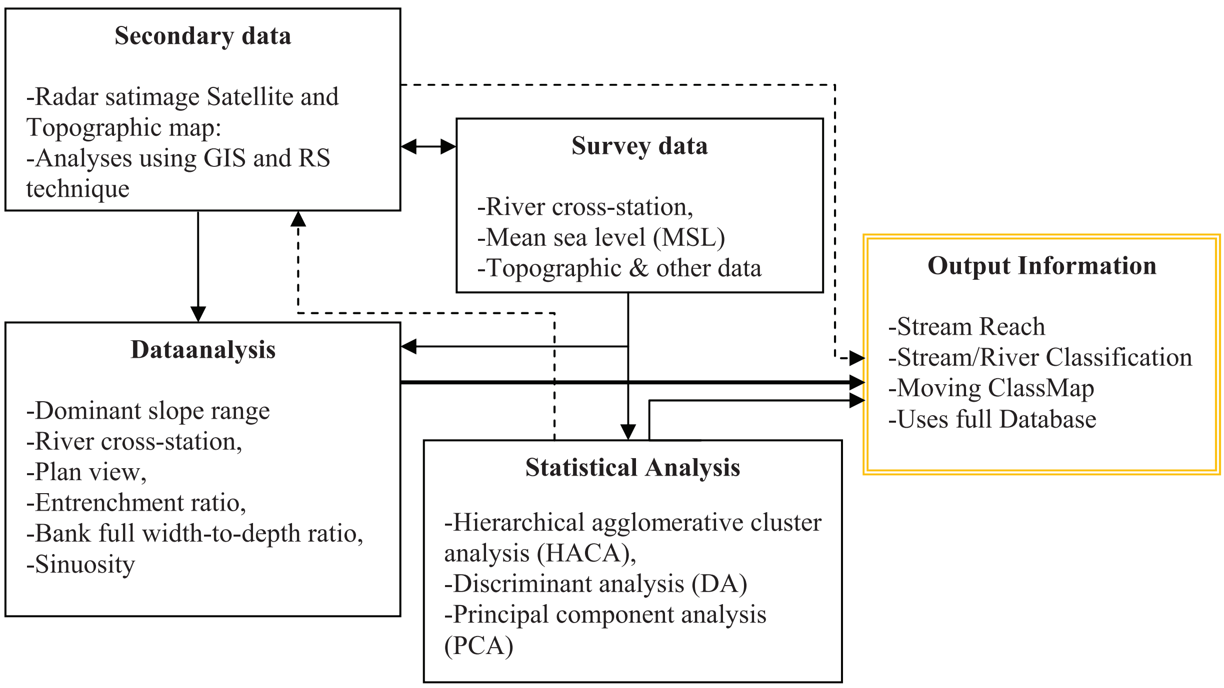


Fig. 5. Framework of river classification study of main Pahang River, Malaysia.

Table 1
Rosgen stream classification system in Stations 1–4 at the main stream of Pahang River, Malaysia

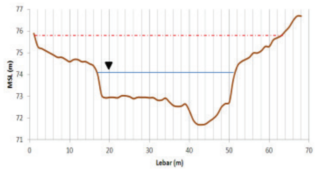
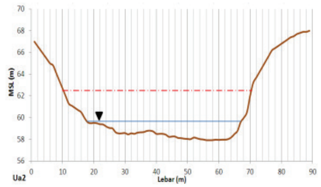
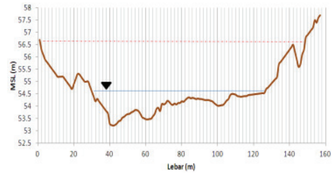
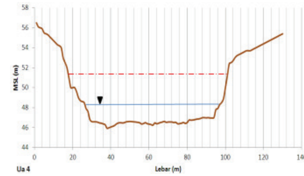
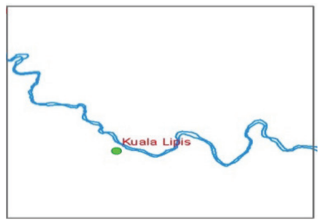
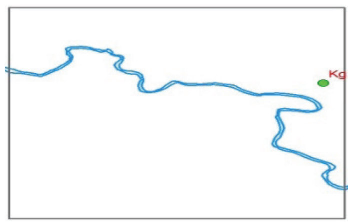
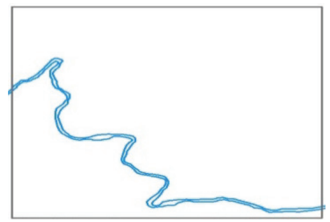
Station No.	S1 (Ua1)	S2 (Ua2)	S3 (Ua3)	S4 (Ua4)
Dominant slope range	0.11	0.09	0.06	0.06
Cross-section view				
Plan view				
Entrenchment ratio	1.35	1.25	2.71	1.11
W/D ratio	20.34	22.47	50.40	37.11
Sinuosity	1.21	1.68	1.66	1.60
Stream types	A-B	A-C	B-C	C-D

Table 2
Rosgen stream classification system in Stations 5–9 at the main stream of Pahang River, Malaysia

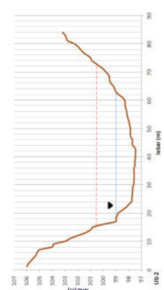
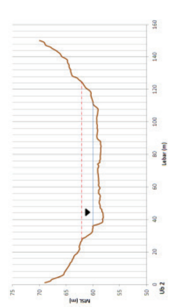
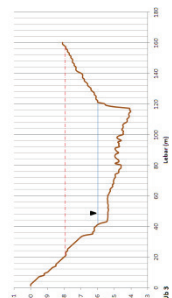
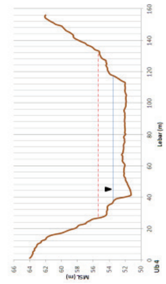
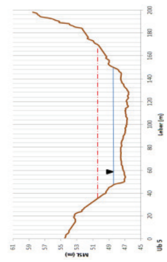
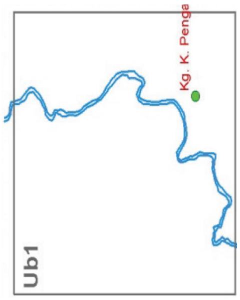
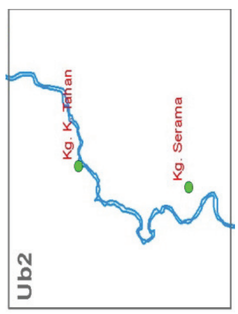
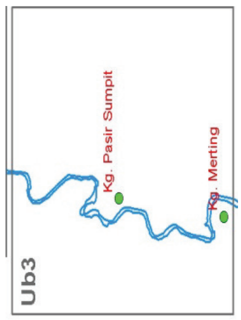
Station No.	S5 (Ub1)	S6 (Ub2)	S7 (Ub3)	S8 (Ub4)	S9 (Ub5)
Dominant slope range	0.11	0.09	0.04	0.03	0.05
Cross-section view					
Plan view					
Entrenchment ratio	1.24	1.26	1.70	1.56	1.29
W/D ratio	37.39	66.08	70.17d	58.82	74.45d
Sinuosity	1.63	1.46	1.50	1.25	1.32
Stream types	A-B	B-A	B-D	B-C	B-D

Table 3
Rosgen stream classification system in Stations 10–13 at the main stream of Pahang River, Malaysia

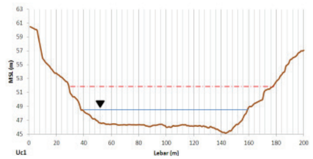
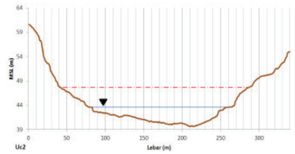
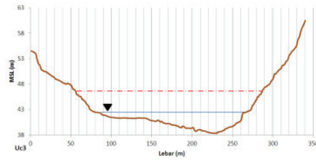
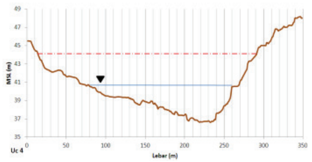
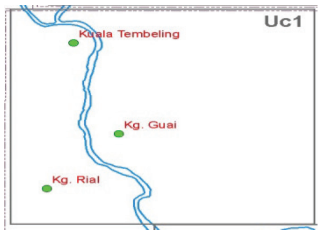
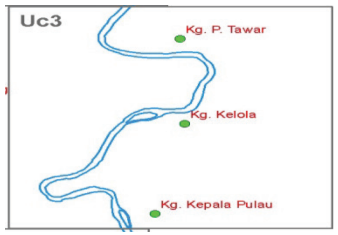
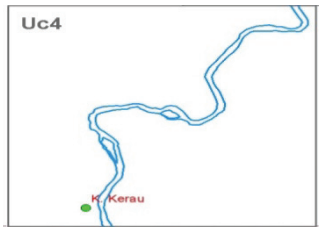
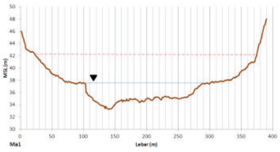
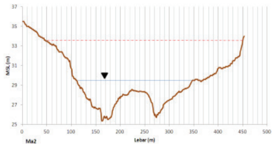
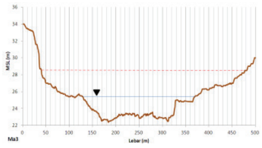
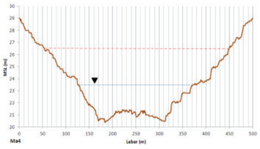
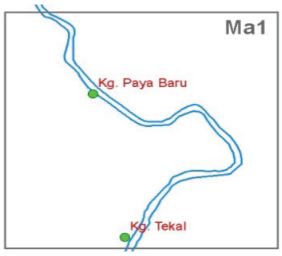
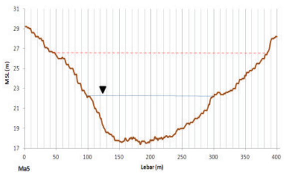
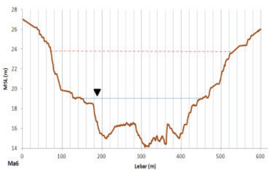
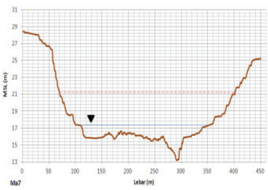
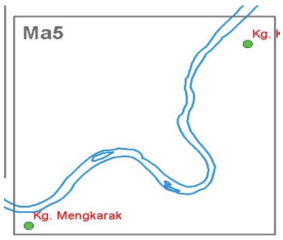
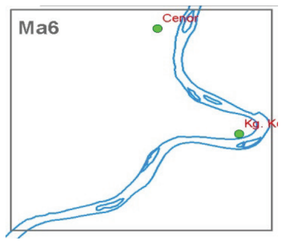
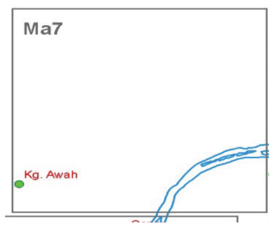
Station No.	S10 (Uc1)	S11 (Uc2)	S12 (Uc3)	S13 (Uc4)
Dominant slope range	0.05	0.01	0.01	0.02
Cross-section view				
Plan view				
Entrenchment ratio	1.22	1.36	1.26	1.54
W/D ratio	51.70	76.59	85.58	83.72
Sinuosity	1.21	1.59	1.81	1.48
Stream types	B-A	C-D	D-E	D-B

Table 4
Rosgen stream classification system in Stations 14–20 at the main stream of Pahang River, Malaysia

Station No.	S14 (Ma1)	S15 (Ma2)	S16 (Ma3)	S17 (Ma4)
Dominant slope range	0.03	0.08	0.04	0.02
Cross-section view				
Plan view				
Entrenchment ratio	1.85	1.67	1.76	1.55
W/D ratio	76.92	125.65	130.89	130.61
Sinuosity	1.63	1.29	1.22	1.46
Stream types	G-F	D-B	D-B	D-C
Station No.	S18 (Ma5)	S19 (Ma6)	S20 (Ma7)	–
Dominant slope range	0.01	0.03	0.03	–
Cross-section view				–
Plan view				–
Entrenchment ratio	1.69	1.52	1.29	–
W/D ratio	62.81	108.63	106.67	–
Sinuosity	1.45	1.52	1.08	–
Stream types	D-C	D-F	D-F	–

application of the optimum spatial sampling strategies can easily be implemented since this kind of analysis provides a reliable classification. This is due to the fact that the concept used in this method is truly based on the homogeneity characteristics of observation, which are put into their own classes [35,36].

The classification of plots obtained from HACA was further confirmed via DA. Purposely, this method was applied to study the spatial variation among the different regions. In this study, DA was employed in the raw data that are classed into three main groups obtained by HACA. Fig. 7 shows that the observation on the factor axes confirmed that the river

Table 5
Rosgen stream classification system in Stations 21–24 at the main stream of Pahang River, Malaysia

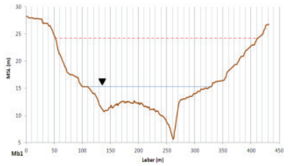
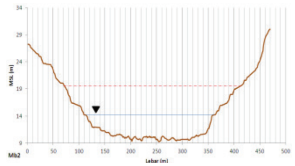
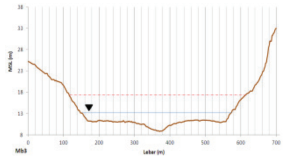
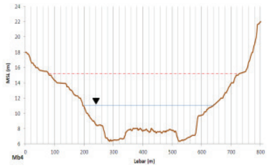
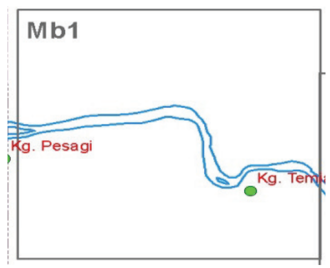
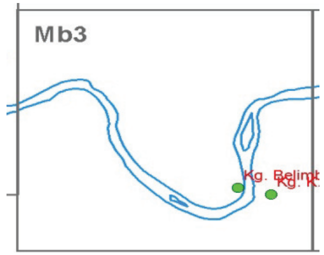
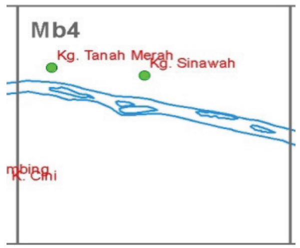
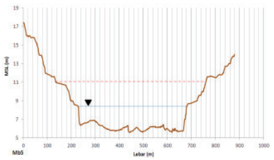
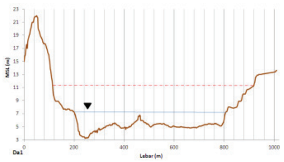
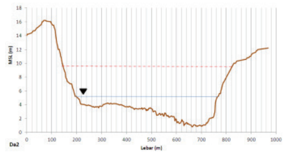
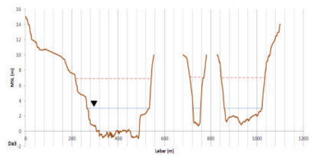
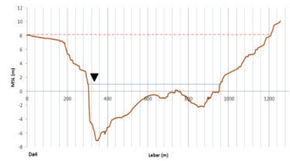
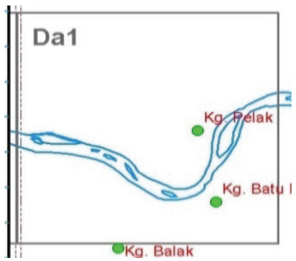
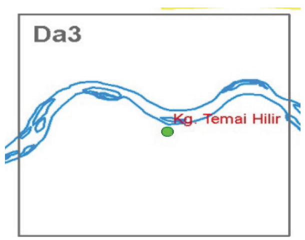
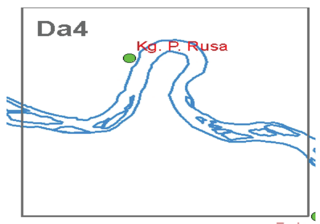
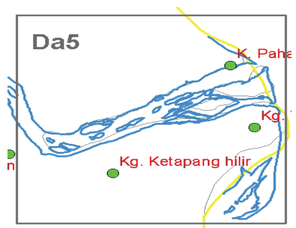
Station No.	S21 (Mb1)	S22 (Mb2)	S23 (Mb3)	S24 (Mb4)
Dominant slope range	0.02	0.01	0.01	0.02
Cross-section view				
Plan view				
Entrenchment ratio	1.56	1.36	1.17	1.47
W/D ratio	73.72	70.36	188.39	144.26
Sinuosity	1.24	1.16	1.72	1.01
Stream types	D-B	D-F	D-F	D

Table 6
Rosgen stream classification system in Stations 25 to 29 at the main stream of Pahang River, Malaysia

Station No.	S25 (Da1)	S26 (Da2)	S27 (Da3)	S28 (Da4)	S29 (Da5)
Dominant slope range	0.02	0.01	0.02	0.02	0.02
Cross-section view					
Plan view					
Entrenchment ratio	1.40	1.34	1.19	1.09	1.86
W/D ratio	200	274.77	253.33	196.36	203.11
Sinuosity	1.28	1.04	1.23	1.62	1.16
Stream types	D–F	D	D and C	D and C	D and DA

classification along main of the Pahang River were very well and clearly differentiated on the factor axes extracted from the original explanatory variables.

Based on the results in Table 7, the confusion matrix for the estimation sample to DA spatial variations shows 100.00% corrected for all river factors on classification along main stream of Pahang River. It explains that the classes from HACA classification are clear and can be accepted with confidence for river classification at the main Pahang River.

The PCA was being applied on the data sets, purposely to identify the most important parameters that influence the classification of identified regions in the study area. Based on the results, there were two PCs with eigenvalues greater than 1 generated from the principal component analysis. The data were rotated by using varimax rotation to acquire the

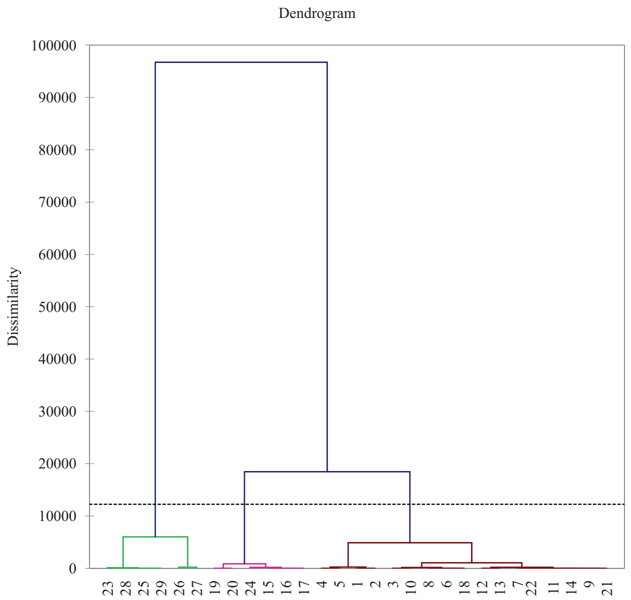


Fig. 6. Classes of river based on homogeneity characteristics.

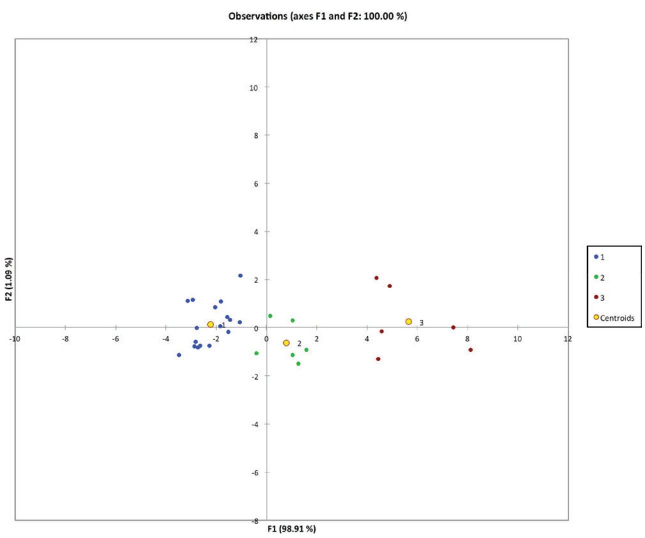


Fig. 7. Observations on the factor axes chart on discriminant analysis (DA) study.

new group of varimax factor and the value of greater than 0.7 was considered for interpretation. Table 8 portrays the correlations between variables and factors after varimax rotation for Pahang River classification data and Figs. 8(a) and (b) shows the illustration of biplot and variables of factor loading after varimax rotation study at main river of Pahang River, Malaysia.

Correlations between variables and factors after varimax rotation for Pahang River classification show that D1 indicates 0.796 strong positive loadings on dominant slope range. However, bankfull W/D ratio factor has strong negative loadings of −0.868. This indicates that these two factors are inconsistent with each other where the higher of dominant slope range, getting narrower for bankfull W/D ratio at this along river and same for the vice versa.

From the results of D2, the total variance was 0.985 with the strong coefficient factor was dominated by the entrenchment ratio. This factor was a big indicator for the river classification where a computed index value, which is used to describe the degree of vertical containment of a river channel (width of the flood prone area at an elevation twice the maximum bankfull depth/bankfull width), can identify the river characteristics to geomorphic characterization.

HACA classification was performed based on the data as presented earlier. The results are tabulated in Fig. 9. It shows that the map of river classification with moving class, where the first class (green color) is upstream reach, second class (yellow color) to middle stream reach and third class (red color) are considered as downstream reach for main of Pahang River. From this classification, this study which estimated the geomorphic characterization on each plot is same and changes movement according to color on the map. This implies that the homogeneity characteristic of problems occurred within its own class.

Fig. 10 shows the plan view and longitudinal view for main Pahang River. Clustered in green color class, it is

Table 7
Confusion matrix for the estimation sample to DA spatial variations in Pahang River, Malaysia

Classes of Pahang river	1	2	3	Total	% Correct
1	17	0	0	17	100.00%
2	0	6	0	6	100.00%
3	0	0	6	6	100.00%
Total	17	6	6	29	100.00%

Table 8
Correlations between variables and factors after varimax rotation for Pahang River classification

Parameters	D1	D2
Dominant slope range	**0.796**	−0.145
Entrenchment ratio	0.022	**0.985**
Bankfull width-to-depth ratio (W/D ratio)	**−0.868**	−0.140
Sinuosity	0.557	0.108

Note: Bold indicates significant values (>0.75)

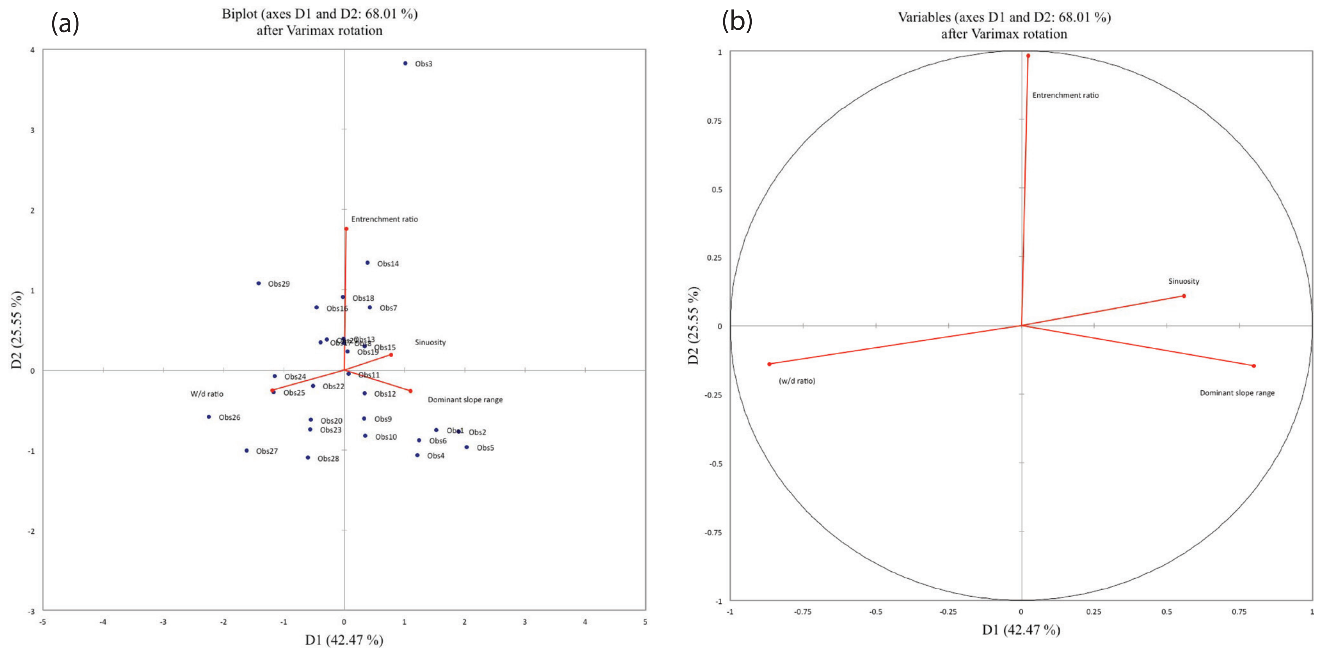


Fig. 8. (a) Biplot of factor loading after varimax rotation study and (b) variables of factor loading after varimax rotation study.

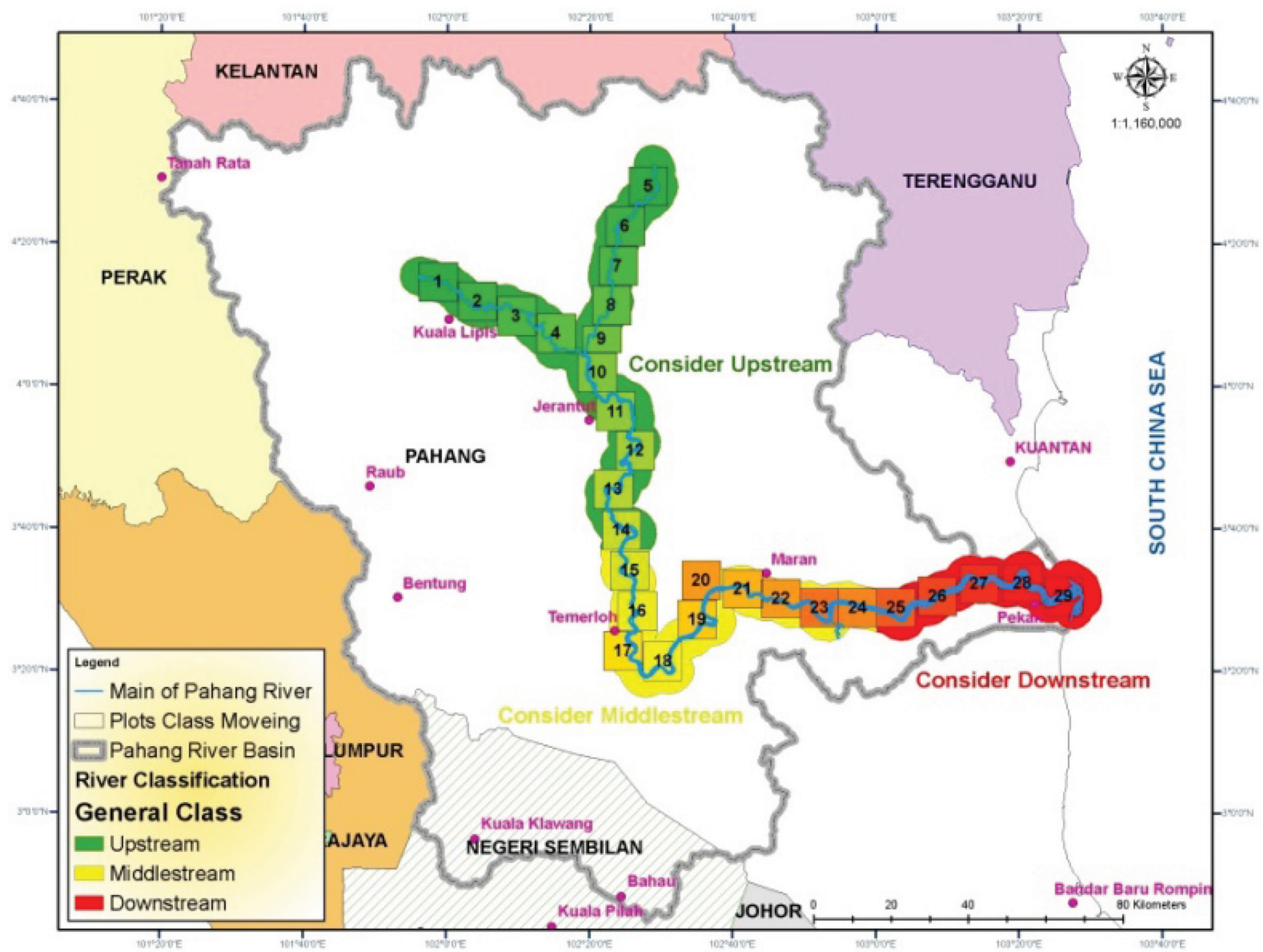


Fig. 9. Map of river classification with moving class using GIS.

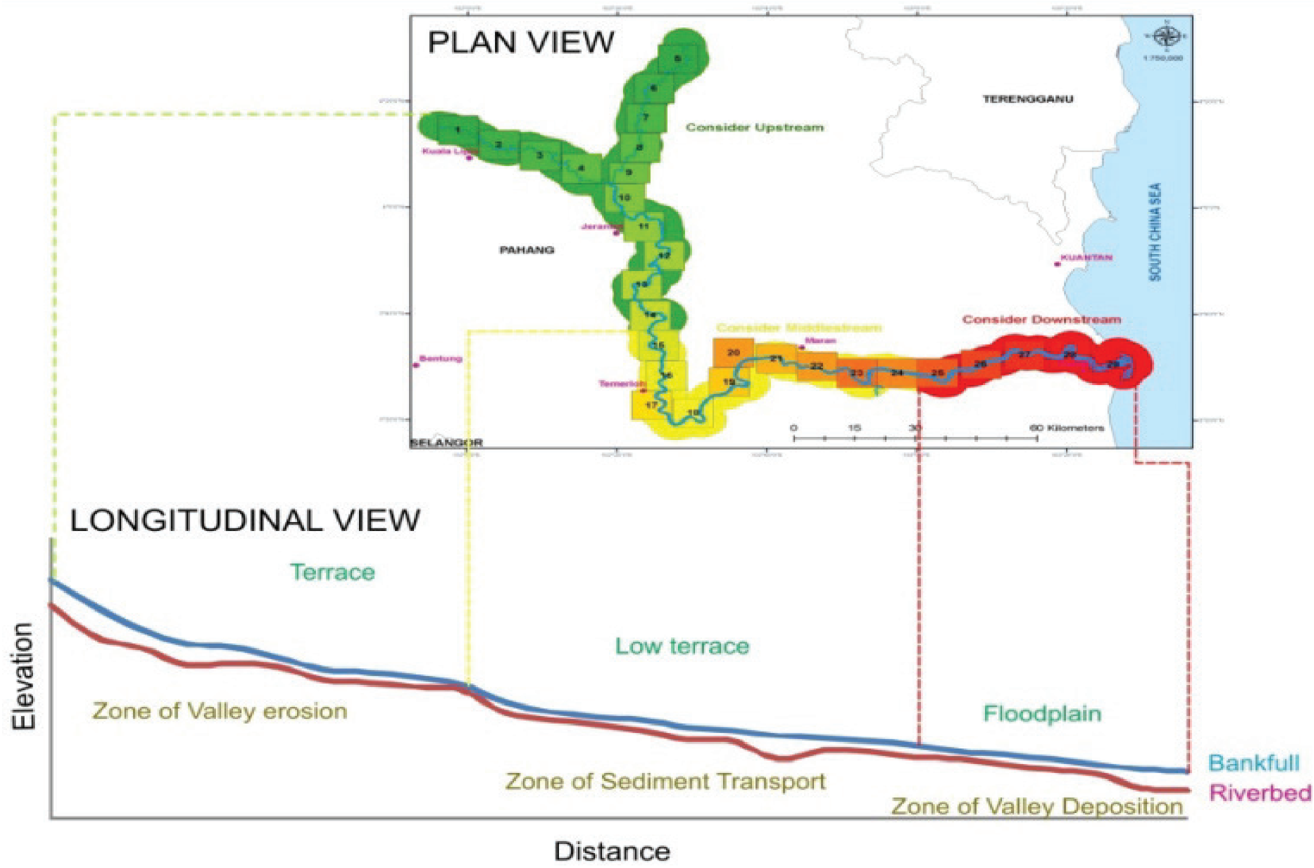


Fig. 10. Plan view and longitudinal view for main Pahang River cluster.

moderately entrenched, moderate gradient, riffle-dominated channel, with infrequently spaced pools, stable banks, and very stable plan and profile. It also has a moderate relief, colluvial deposition, moderate W/D ratio, narrow, gently sloping valleys, and rapid predominated width scour pools [37] where in this class it is also being pointed within terrace and valley of erosion zone. Yellow colour or middle stream reach has low gradient, meandering alignment, riffle/pool and alluvial channels with broad, well-defined floodplains, broad valley width terraces, usually in association with floodplains, alluvial soils, slightly entrenched with well-defined meandering channels, and riffle/pool on bed morphology. It is also in low terrace on land near the channels and sediment transports zone [38–42]. For red color class or downstream reach, it has a braided channel with longitudinal and transverse bars, very wide channel with eroding banks, broad valleys with alluvium, steeper fans, glacial debris and depositional features, active lateral adjustment, width abundance of sediment supply, convergence or divergence bed features, have a little aggradational processes, high bedload and high wash load sediment [43]. This class in floodplain areas and valley deposition zone. The description of output data of this study is summarized in Table 9.

In this study, the statistical relationship between the discharge river and stream flow interpreted the effect of plan changes and geometric shape of the river in the study area. Figs. 11–13 show the proportion of positive correlation ($P < 0.05$) between the river discharge and stream flow levels for each station (hydrological stations) Yap River ($R^2 = 0.852$), Temerloh ($R^2 = 0861$) and Lubuk Paku ($R^2 = 0.925$). These positive correlations proved that the rising of river water level will cause the increasing in the rate of river discharge of a stream. The climatic condition changes may affect the rates of geomorphic processes that then drive changes in basin characteristics. From the result, the variability from the highly seasonal rainfall in these areas, and the high degree of variation from year to year. Besides that, the characteristics of geomorphology factors, important aspects of climate, should be considered if conditions become unequilibrium such as any decrease that might occur in the annual rainfall amount, the duration of rainfall events, and any increase in the intervals between rainfall events.

4. Conclusion

Stream or rivers are complex natural systems. A necessary and critical task towards the understanding of these complex systems is to continue the stream or river systems research. This study attempted to understand and classify a group of geomorphology characterization criteria into a greater understanding convenient such as upstream reach, middle stream reach, and downstream reach for main river of Pahang River. This study has considered the main criteria for classification that are dominant slope range, river cross-station, plan view, entrenchment ratio, bankfull width-to-depth ratio, and sinuosity as representing the criteria

Table 9
Main data for main of Pahang River, Malaysia

Plots	Stream types Rosgen 1 (1996)	Classification zone	Monitoring zone, riverbed characterization
1	A-B	Upstream reach	Erosion
2	A-C	Upstream reach	Erosion
3	B-C	Upstream reach	Erosion
4	C-D	Upstream reach	Erosion
5	A-B	Upstream reach	Erosion
6	B-A	Upstream reach	Erosion
7	B-D	Upstream reach	Erosion
8	B-C	Upstream reach	Erosion
9	B-D	Upstream reach	Erosion
10	B-A	Upstream reach	Erosion
11	C-D	Upstream reach	Erosion and sediment transports
12	D-E	Upstream reach	Erosion and sediment transports
13	D-B	Upstream reach	Erosion and sediment transports
14	G-F	Upstream reach	Erosion and sediment transports
15	D-B	Middle stream reach	Erosion and sediment transports
16	D-B	Middle stream reach	Sediment transports
17	D-C	Middle stream reach	Sediment transports
18	D-C	Middle stream reach	Sediment transports
19	D-F	Middle stream reach	Sediment transports
20	D-F	Middle stream reach	Sediment transports and deposition
21	D-B	Middle stream reach	Sediment transports
22	D-F	Middle stream reach	Sediment transports
23	D-F	Middle stream reach	Deposition
24	D	Middle stream reach	Sediment transports and deposition
25	D-F	Downstream reach	Deposition
26	D	Downstream reach	Deposition
27	D and C	Downstream reach	Deposition
28	D and C	Downstream reach	Deposition
29	D and DA	Downstream reach	Deposition

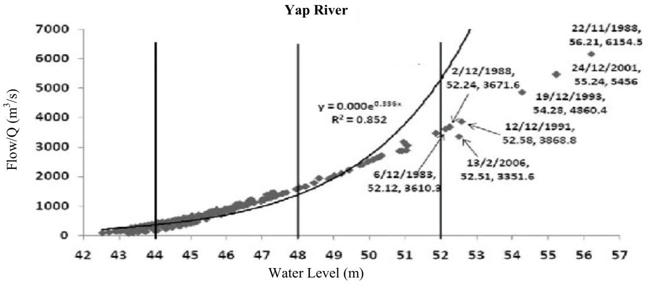


Fig. 11. Stream flow condition in Yap River (1983–2006).

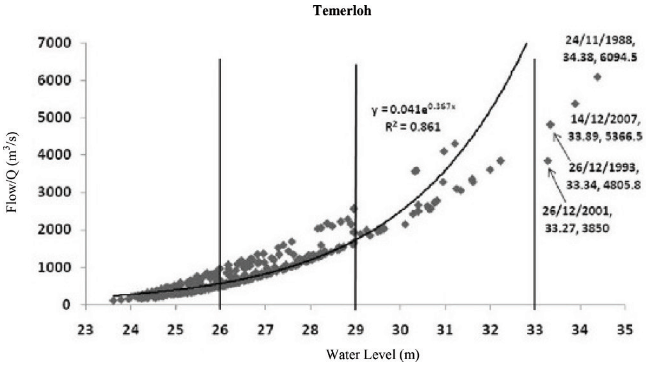


Fig. 12. Stream flow condition in Temerloh (1988–2007).

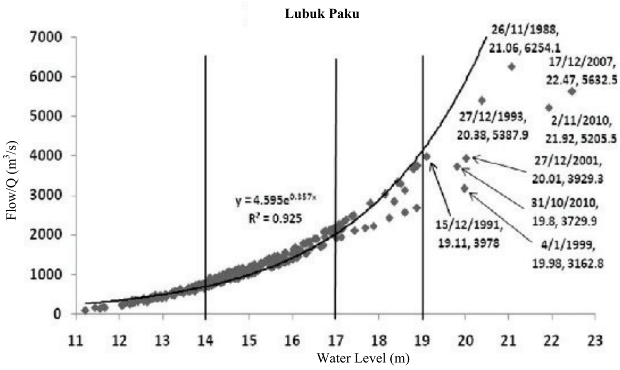


Fig. 13. Stream flow condition in Lubuk Paku (1988–2007).

selected for this study research. To assist the success of this study, the envarometric techniques were adopted to investigate the spatial variability of all the main criteria to this classification.

The results were collected using HACA analysis with further proof by DA (very well and clearly differentiated on the factor axes extracted from the original explanatory variables) and PCA analysis with strong coefficient where the main of Pahang River was classed into three main clusters as upstream reach, middle stream reach, and downstream reach with moving clusters change. This study produced the basic information or database to understand the characteristics or behavior of these parts of this river system. However, the water resource managers who are constantly required to make decisions and timely predictions lack the luxury of a complex and thorough basic information or database. Therefore, another goal for researchers and managers of this study is to integrate properly on what has been learned about rivers into a management decision support system.

The utilization of quantitative channel morphological indices with further proof by envarometric techniques for a classification procedure ensures for consistency in defining main river at Pahang River among observers for a great diversity of potential applications. The classification presented here may be the first approximation of a Pahang River system in Malaysia. Therefore, this classification system can be expected to provide a better communication among those studying river systems and to promote a better understanding of river processes. This study also has potential in helping out to put principles into practice. Most importantly, is also very imperative to local authorities to make decision according to the cluster or guidelines for future study of Pahang River, Malaysia, specifically and for tropical river generally.

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