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ORIGINAL ARTICLE

Analysis of meander evolution studies on effect from land use and climate change at the upstream reach of the Pahang River, Malaysia

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Abstract Hydrogeomorphologically, the study of river meandering provides information on the tendency of rivers to reach and form a state of equilibrium. The process of meander changes is important in order to identify the environment-related causes that occur naturally or vice versa. Sedimentation, erosion, flood, and water quality problems usually are being specifically studied, but in a broad view, changes in the platform of the river affect all the

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problems that occur. This article discusses the effects of the meanders evolution changes from land use and climate change in the upstream of Sungai Pahang in over 61 years from 1932 to 1993. Based on Geographical Information System (GIS), the topographic maps, scaled to 1:50,000 in geo-reference, were overlaid and digitalized. The main alignments of the upstream reach from those years were superimposed, and the changes were identified based on sinuosity index. In this task, the study areas were divided into two major plots for river plan classification. The results indicated that the average of alignment on the sinuosity index is 1.24 to 1.48 in plot A, while in plot B, the results are not stable. Based on historical results, a very significant change of meander was identified in the subplot Ua3 in plot A, where 21.2 % segments were recorded with high changes. This could be associated with significant exploration at hilly areas in the Cameron Highlands. Large-scale changes in land use pattern are coupled with global climate change where total rainfall recorded was at 2,760 mm in plot A on the year 1993. While for the plot B segment, the percentage of meander changes is 41.5 % versus plot A which is 86.7 %. This is due to the fact that plot B is the forest reserve and national park, areas with natural environment, possessing *lithosols* characteristic soils in the upper plot B area, and the trend of land use change (forested areas) is substantially lower than in plot A, with a 10 % difference. The aim of this study is to understand the impact of the land use changes due to climatic conditions on the meander evolution changes at the upstream reach of the Pahang River and suggest a number of solutions to mitigate or adaptation strategies to cope with those changes in the future.

Keywords River platform change · Sinuosity index · River planform · GIS applications · Upstream of Pahang River

1 Introduction

Water is the main source of livelihood in the world and is highly dependable for food, flora and fauna, human activities and the economic sector, the environment, and so forth. Rivers are the major water source for life on the globe and plays an important role in the development of human civilization (Toriman et al. 2009, 2012a; Sulong et al. 2005; Barry et al. 1969). The study of the rivers are to create a discipline of knowledge such as on flood, erosion, sedimentation, water quality, and other studies of streams which are found often being meticulously studied today (Ashmore and Rennie 2013; Wuriyati 2007). However, these studies are much more focused and specific to a subfield (e.g., flood, erosion, sedimentation, water quality, etc.). In a broad view, this entire problem can be identified by geometric and river plan changes, whether as a cause of natural occurrence or human disturbance. Rivers display a dynamic pattern of meandering over time. Channel stability is the ability of the stream to transport the flows and sediments of its watershed in such a manner that the dimension, pattern, and profile of the rivers are maintained without aggrading or degrading (Kamarudin et al. 2009; Toriman et al. 2009; Trimble 1993). The stability status of a river channel can be determined by assessment of the channel platform over time.

In this decade, the scientific world has been witnessing the development of a series of cellular models that simulate the processes operating within river channels and drive their geomorphic evolution which will subsequently lead to the study and discussion of its potential and implications of evolution of river meandering into environmental managements. According to Coulthard et al. (2007) and Coulthard and Van De Wiel (2006), straight and meandering rivers are usually simulated using vector-based models (e.g., Sun et al. 2001, 1996; Howard 1996), which elegantly capture the dynamics of single-thread channels, but which cannot simulate multi-threaded channels. Conversely, braided channels are effectively simulated using cellular-based models (e.g., Murray and Paola 1994; Thomas and Nicholas 2002), which utilize simple local rules to replicate the dynamics of the system, but on the other hand, fail to replicate the lateral dynamics of meandering channels. However, this study goes in the preliminary study level to determine the river plans channel or "meander evolution changes" in the main river at the upstream of the Pahang River with the approach of Geographical Information System (GIS) software.

Generally, climate controls the landscape evolution, but quantitative signatures of climatic drivers have yet to be found in topography on a broad scale Stark et al. (2010). Extreme rainfall and flood events are common, but when the water flow concentrated into primary control on sinuosity causes rock weakness in the river, then the weakness of bedrock channel walls and their weakening by heavy rainfall together modulate rates of meander propagation and sinuosity development which finally leads to the meander evolution process. The effects of climate change are probably the most important natural factors controlling fluvial hydro system equilibrium and, therefore, river channel change (Othman et al. 2010; Toriman et al. 2009). Leopold et al. (1964) used two simple and general parameters namely, mean annual temperature and mean annual precipitation to characterize the climate. They also emphasized that both magnitudes and frequency of the climatic factors strongly control the significance of different geomorphic processes.

In this research, the rainfall information is studied to unravel their effects on the upstream of the Pahang River channel changes. Various catchment developments and project features such as deforestation, urbanization, channelization, and flow diversion are examples of anthropogenic factors that may increase flow discharges. Increased discharges tend to cause cross section enlargement, accelerated meander migrations and eventual lengthening of meanders, and longitudinal profile change (Gilvear et al. 2000; Hooke and Redmond 1992). The main objective of this study is to determine the effect of the land use changes into the meander evolution changes at the upstream reach of the Pahang River in Malaysia. This study is also supported by some data e.g., topographic maps (from the years 1932 to 1993), land use, soil map, and rainfall data. However, due to limitations on the limited historical data, the study used any obtainable yet reliable data for the success of this study and served as a catalyst to initiate and trigger the idea for such studies in Peninsular Malaysia.

2 Materials and methods

2.1 Study area

Pahang River or in Malay language, Sungai Pahang, is the longest river in Peninsular Malaysia with a length of 459 km, and its upstream is located in the main range of Titiwangsa. Sungai Pahang which is located at Pahang River Basin is the main channel responsible for draining the water from this basin into the South China Sea (Toriman et al. 2012b; Sulaiman et al. 2010). Sungai Pahang is divided into the Tembeling and Jelai Rivers and both rivers meet at a confluence at Kuala Tembeling, which is located 300 km away from the estuary of Sungai Pahang (Kuala Pahang). The river meanders through townships such as Jerantut, Temerloh, Maran, Bera, and Pekan and eventually flows into the South China Sea which is located on the east coast of Peninsular Malaysia (Gasim et al. 2013; Lun et al. 2011). The length of this river thus reflects on the vast size of these basin areas, therefore, various problems arose, faced by the Sungai Pahang and surrounding communities (Fig. 1).

From the impact of historical global climate change, multiple problems have arisen that are expected in the evolution of the meander process at the Pahang River. For example, flood is

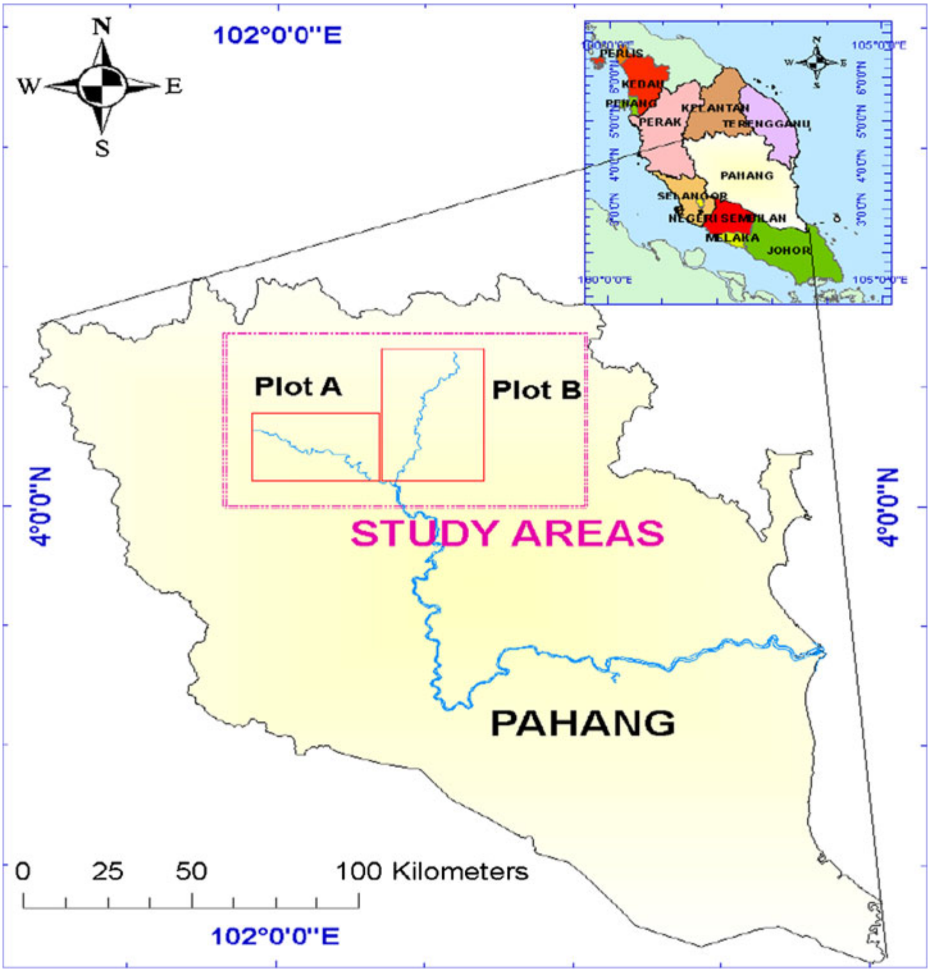

Fig. 1 Location of study areas at Sungai Pahang

one of the major problems that affect the community and river meander change. In Sungai Pahang, one of the frequent flood disasters is at the downstream area (at Pekan district). Historically, the largest flood event had been recorded in Pahang during 1926 (DID 1974). According to Nossin (1965), observation after the flood event showed the river plan change was quite significant which occurred in the downstream area of the Pahang River at Sungai Pahang Tua (downstream of Pahang River) because of sedimentation. This phenomenon was also supported by other research studies covering other areas which produced quite similar results (Armas et al. 2013; Solihuddin 2010; Aswathy et al. 2008; Mikhailov et al. 2004). On December 2007, one of the worst floods was recorded again in Pahang. Various impacts were faced by the local community and the river itself, such as the destruction of properties, high sedimentation at the downstream area, and changes on the geometric and river meander plan at Sungai Pahang (Ghani et al. 2012; Toriman et al. 2012c; Hashim et al. 2007; Mstar Published 2007). Generally, sedimentation problems that occurred at the downstream area are a result of problems in the upstream area. Therefore, this study focuses only on meander changes that occur in the upper reaches of the Sungai Pahang, which is one of the main causes of the problems in downstream areas.

2.2 Methods

In this study, the Geographic Information System (GIS) was used to identify the historical meander changes. Topographic maps with a scale of 1:50,000 m, which is a set of topographic maps of 1932 and 1993, were combined to include all the Sungai Pahang river basin. Next, each set of maps through the process of geo-reference with Projection: Kertau_RSO_Malaya_Meters and digitalization for river using polyline and polygon tool for the basin. As the study requires high accuracy, the validation of the geo-reference process was conducted before the digitalization process was carried out in this process to ensure total RMS error is minimized and adopted based on the scale used (Toriman 2008; Vipin et al. 2012). For the validation of the analyzing of databases in this study, the rectified 1932 and 1993 maps, all maps using similar scale, were superimposed to detect reaches which registered changes. These changes were stored as new themes for the subsequent sinuosity analysis. One of the advantages of using GIS is that highly accurate measurements between points can be obtained. It also provides a rapid and convenient technique to compare the rectified map (year 1932) with the base map (year 1993). Fixed reference points which could be identified from the two maps were located, and their coordinates were noted to the nearest 0.1 m. The differences between the coordinates (base map minus rectified map) were determined from X and Y directions. However, errors during the digitizing and rectification processes could still be significant and these can be evaluated using equations (1) and (2). Equation (1) provides the systematic error (s) which is defined as:

$$s = \frac{\sum x}{n} \tag{1}$$

Where, x is error at n reference point. If $s=0$, then the errors are random. However, if s were introduced, most likely during map rectification, then the value of s indicates the degree of channel 'shift' that has taken place. Secondly, the Root Mean Square Error (RMSE) is calculated as:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} x_i^2}{n}} \tag{2}$$

Where, x_i is the error at n reference point. RMSE provides the average error by which coordinates of the same point (or tics) on the two or more maps deviate. Such errors must be considered when measuring a shift in the channel alignment over the observation period. With GIS, the accuracy of the rectified maps could be measured against the base map by fixing several geo-reference points. The differences between the coordinates (base map minus rectified map) were determined in both X and Y directions.

Superimposed process for major alignment of the Pahang River to the following 2 years was carried out to identify evolutionary changes that had occurred on meanders in over 61 years. Additionally, through a GIS database, the analysis of sinuosity index will be conducted. Overall, this method of study can be summarized as in the (Fig. 2) conceptual framework.

Quantitative analysis then were undertaken in order to examine river channel platform changes along the study of the upstream of the Pahang River. It involved determining and measuring the channel sinuosity which is the channel length over valley length. In this respect,

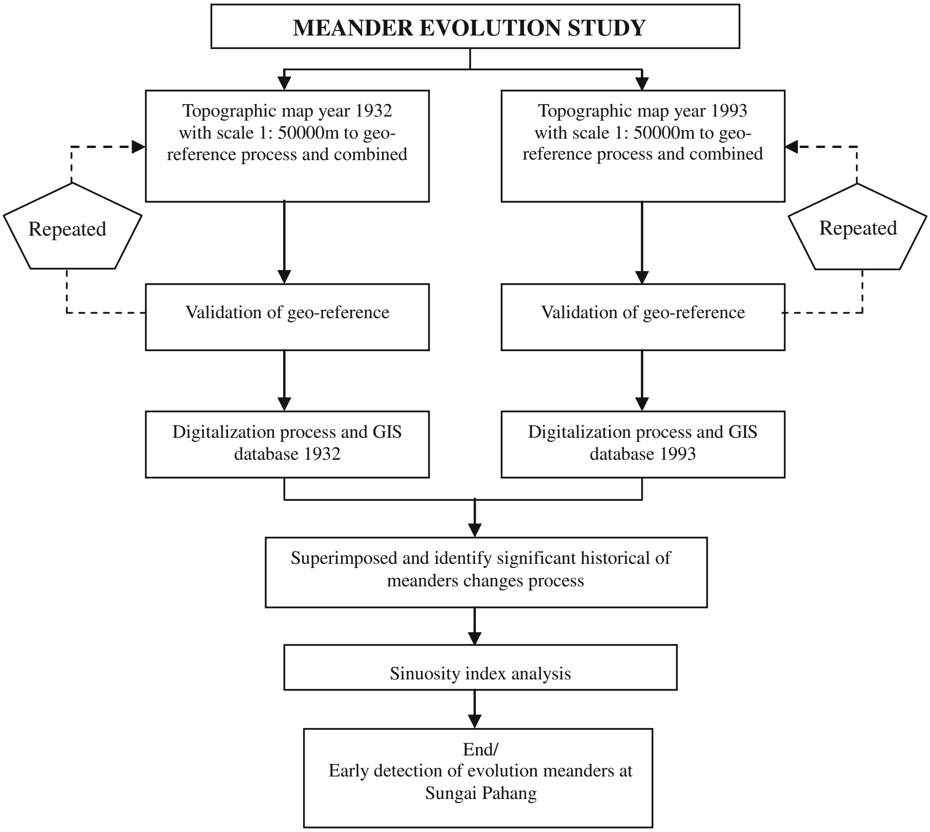

Fig. 2 Framework of the meander evolution study analysis

sinuosity index is a key indicator to identify the stability of a river channel (Hooke and Redmond 1992; Toriman et al. 2006; Rosgen 1994). Thus, the analysis was performed to determine the type of stability sinuosity index and to categorize the evolution that took place in the main alignment on the river (See Table 1). The process of sinuosity measurement involved measuring the valley length as a straight line drawn from the starting point to the end point of each subreach and the channel length which was a meandering line along the channel axis. The calculation of sinuosity index which was carried out using the database was analyzed through GIS and following this formula:

$$Sinuosity\ \ Index(SI) = \frac{Channel\ \ Length\ (L)}{Valley\ \ Length\ (Z)} \tag{3}$$

3 Results and discussion

Based on the analysis, Fig. 3 shows the evolution of meanders that occurred in plot A, Jelai River in Sungai Pahang for 61 years. This plot is the most significant area of change from plot B.

Table 1 Type of meander evolution stability

Sinuosity index (SI)	Stability type	Summary
<1.2	Stable	S
>1.2	Unstable	US
>1.5	Very unstable	VUS

Adapted from Rosgen (1996), pp: 5–6

According to Table 2, an average of meander type stability status in the major river for plot A, Pahang River, was unstable in the period of 1932 and 1993, which recorded 1.48 and 1.40, respectively. However, the subplot Ua4 1993, Ua9 1932, and Ua9 1993 were stable, in relation with the fact that the area had been approaching the meeting point in this river with a larger width of the river from upstream areas. Naturally, the upstream area is an area of highland that normally possess very fast current velocity and will produce an increasingly sharp meander (Richard et al. 2005; Rinaldi et al. 2005). Therefore, the highland areas usually have an unstable sinuosity index.

In 1993, significant meander changes occurred in subplot Ua2, Ua3, Ua4, Ua5, Ua7, Ua8, and Ua9 with percentage entries of 6.6, 21.2, 15.2, 6.7, 10.8, 17.4, and 5.5 %, respectively (Fig. 4). This evolution happened due to the effect of the opening and exploration of significant hills in the Cameron Highlands (Othman et al. 2010). According to Van Hecke and Van Der Linde (2011), the Cameron Highlands had been explored as early as the year 1925 where the areas were developed solely for agriculture use. After 1 year later, construction started on a road that connected Tapah and the upper plateaus. After that, the urbanization in the Cameron Highlands had been developing rapidly (see Fig. 11). Opening of forest areas that produced the large-scale open areas without any mitigation will result in a rapid surface runoff directly into the main river (Pulak 2012). This is because the trees that act as agents of interception, precipitation, and detain runoff water into groundwater storage have been removed. Therefore, the surface runoff with sediments will continue into the main river, and moreover, the upper reaches have a high rate of rainfall depth with high gravity and some waterfall which would

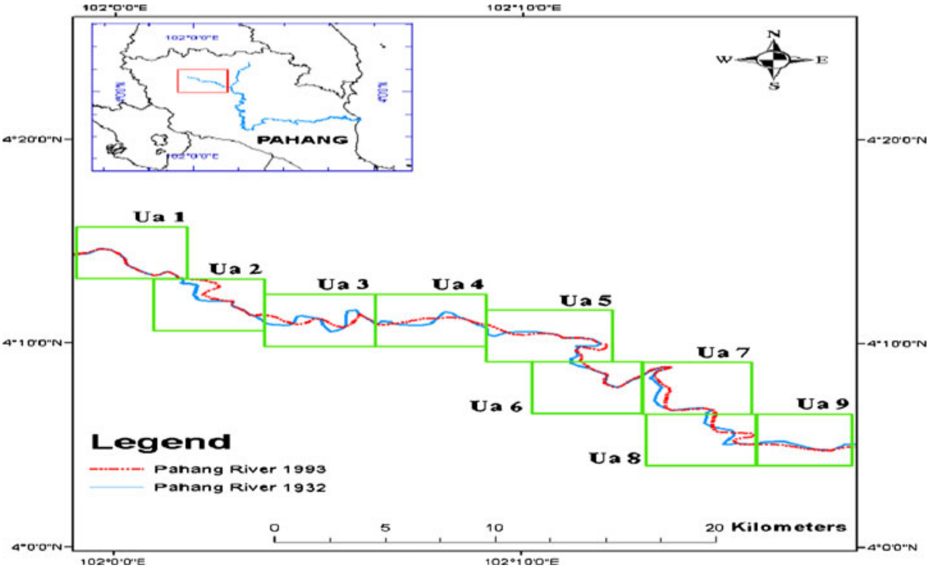

Fig. 3 Meanders evolution map for plot A from 1932 to 1993

Table 2 Type and frequency of meander changes for plot A from 1932 to 1993

Subplot no.	Stability type	1932			Stability type	1993		
		L	*Z*	*SI*		*L*	*Z*	*SI*
Ua1	Unstable	6,439.11	5,000.67	1.29	Unstable	6,438.33	5,000.34	1.29
Ua2	Unstable	6,461.82	5,336.96	1.21	Unstable	6,448.10	5,001.26	1.29
Ua3	Very unstable	8,545.61	5,029.78	1.70	Unstable	6,886.00	5,128.84	1.34
Ua4	Unstable	6,375.61	5,096.87	1.25	Stable	5,386.75	5,074.47	1.06
Ua5	Very unstable	8,703.31	4,899.02	1.78	Very unstable	9,081.30	5,471.49	1.66
Ua6	Unstable	5,130.65	3,424.57	1.50	Very unstable	4,678.42	3,019.83	1.55
Ua7	Very unstable	8,855.23	4,575.65	1.94	Very unstable	8,437.18	4,868.33	1.73
Ua8	Unstable	5,189.14	3,474.23	1.49	Very unstable	5,718.42	3,267.50	1.75
Ua9	Stable	4,850.18	4,415.45	1.10	Stable	4,535.83	4,382.04	1.04
Average	Unstable	60,550.65	41,253.2	1.48	Unstable	57,610.34	4,1214.11	1.40

The units used are in meters

increase the speed of the river velocity. Finally, it will initiate the erosion process which will lead to a tremendous impact on the meander history.

This fact was further strengthened with the analysis of the land use change data (Fig. 5). Due to the limitations of the data for the year 1932, this study adopted the land use data from the Department of Agriculture of Malaysia from the years 1984–2004 to observe the trend of the land use changes. For plot A, reduction of the forest area had increased by 14 % which was 84 % from 70 % in the years 1984–2004, the farming area had escalated by 7 % from 12 to 19 %, and urban areas and fields increased by 8 % which was from 2 to 10 % in 2004. The increase of the land use change from forestry into urban areas with the reduction of the covered areas affected the river meanders evolution. Meanwhile, the trend of land use change for plot B was substantially lower than plot A as only 4 % reduction occurred in the forest area (which is 97 to 93 % in the years 1984–2004) for 20 years.

For the base soil characteristic in these areas, the superimposing of the soil map from the Department of Agricultural Malaysia with the main map of the Pahang River had been done

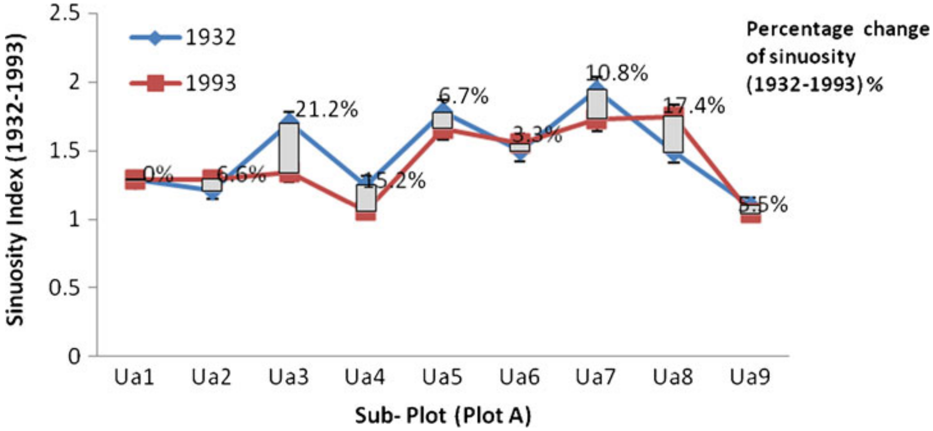

Fig. 4 Percentage of meander evolution for plot A from 1932 to 1993

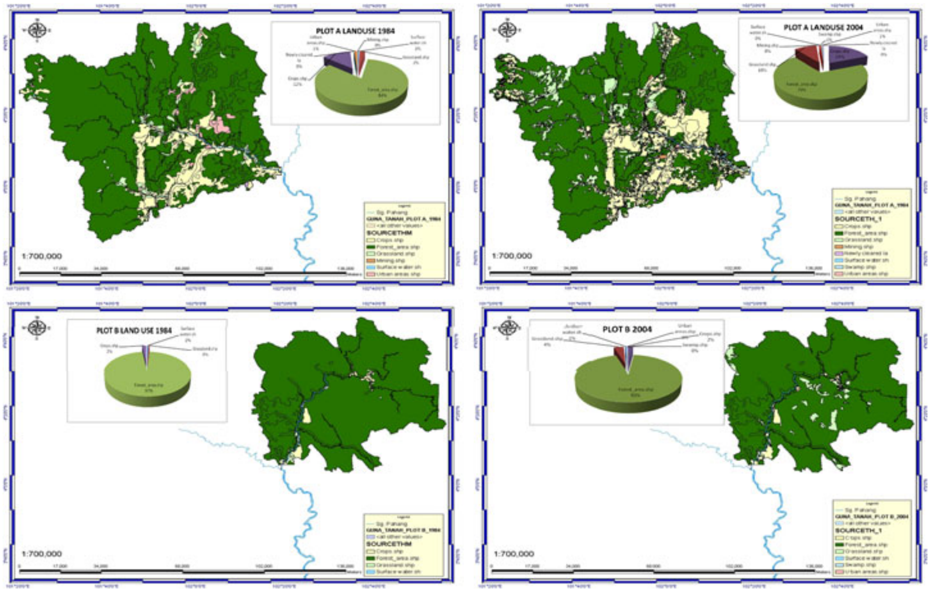

Fig. 5 Analysis of land use changes map for plot A and B from 1984 to 2004

(Fig. 6). The study shows that the base soil characteristic in plot A had more soil from blue color, while in plot B, possessed more soil from striped white on the upper portion and same

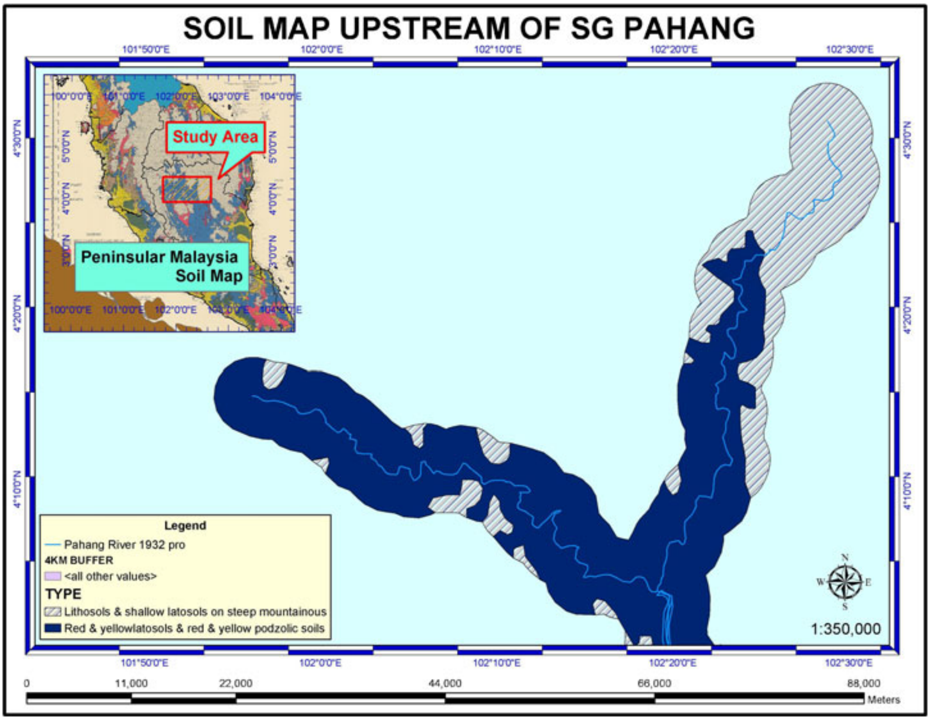

Fig. 6 Analysis of soil map characteristic for plot A and B

blue color for the lower part (Fig. 6) where the blue color is *red and yellow latosols and red and yellow podzolic soils* on gently to strongly sloping land of variable fertility derived from a variety of sedimentary rocks characteristic and the white striped is *Lithosols and shallow latosols* on steep mountainous and hilly land considered unsuitable for extensive agricultural development.

Lithosols (initial rocky soils) are very shallow soils developed in situ from various *noncarbonate* hard rocks. These soils have an AC-R profile. Thickness of AC horizon is less than 10 cm (Reynolds 1971). Soil characteristic in upper plot B areas was stronger from plot A, but as it got lower, it displayed the same characteristics. Therefore, the characteristics of the soil in the study area were also one of the causes of the meanders evolution processes.

For plot B, the Tembeling River flow into the Pahang River which flows from the forest National Park, Ulu Dong Forest, and Gunung Tahan mountain areas where the history of land use differ significantly from plot A (see Figs. 5 and 11). Figure 7 shows the meanders evolution from the years 1932 to 1993 for plot B.

The forest reserve areas still stood as a leading cause of slow meander evolution occurring in the upper reaches B (plot B) at Pahang River; Fig. 7 exhibits no significant difference except in subplot Ub4, Ub5, Ub6, and Ub10. Table 3 shows the type and frequency of meander changes for the years 1932 and 1993 in plot B.

The average of plot B, type and frequency of meander changes for Sungai Pahang in the years 1932 and 1993 were unstable, in which each sinuosity was averaging at 1.30 and 1.24. However, the subplot Ub1 (1932–1993), Ub6, and Ub5 in 1993 were stable. This was due to the condition that subplot Ub1 was the amalgamation of two major tributaries of the Tahan

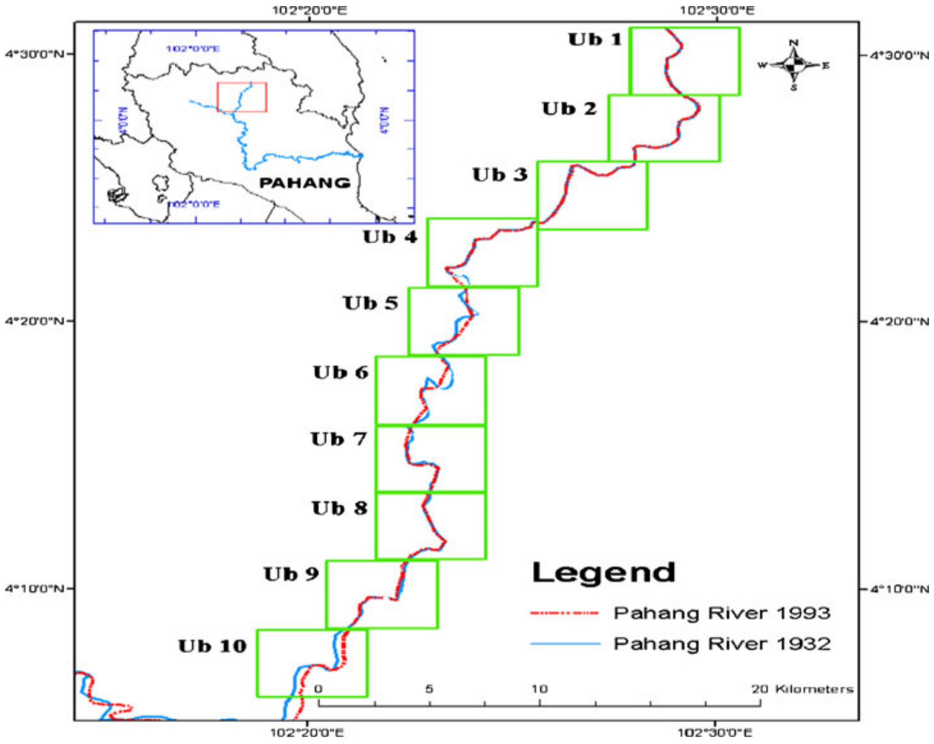

Fig. 7 Meanders evolution map for plot B from 1932 to 1993

Table 3 Type and frequency of meander changes for plot B from 1932 to 1993

Subplot no.	Stability type	1932			Stability type	1993		
		L	*Z*	*SI*		*L*	*Z*	*SI*
Ub1	Stable	5,320.11	4,774.72	1.11	Stable	5,320.11	4,774.72	1.11
Ub2	Unstable	7,037.32	5,141.77	1.37	Unstable	7,037.32	5,141.77	1.37
Ub3	Unstable	7,819.45	6,109.23	1.28	Unstable	7,819.45	6,109.23	1.28
Ub4	Unstable	7,879.45	5,474.82	1.44	Unstable	7,750.40	5,546.32	1.40
Ub5	Unstable	6,544.14	4,938.70	1.33	Stable	5,406.74	4,878.69	1.11
Ub6	Unstable	7,366.17	5,024.98	1.47	Stable	5,824.57	4,897.75	1.19
Ub7	Unstable	6,047.23	4,805.59	1.26	Unstable	5,864.01	4,717.77	1.24
Ub8	Unstable	6,053.33	4,832.78	1.25	Unstable	6,053.33	4,832.78	1.25
Ub9	Unstable	6,440.34	5,437.87	1.18	Unstable	6,440.34	5,437.87	1.18
Ub10	Unstable	6,692.58	5,320.60	1.26	Unstable	6,440.88	5,190.51	1.24
Average	Unstable	60,507.55	46,540.45	1.30	Unstable	57,516.27	46,336.9	1.24

The units used are meters

River and Tembeling River that would produce the largest direct discharge impacts to the riverbanks and meander in the area. For the type of very unstable was not even available in this plot because for the period of 61 years, plot B area had not been experiencing large-scale land clearing activities resulting to the undisturbed natural cycle of the area (Armas et al. 2013; Toriman et al. 2012b). Therefore, the surface runoff and river flow velocity could be controlled naturally. Bank erosion, which is one reason for the meander change was also being controlled naturally through tree roots and existing plants.

Figure 8 displays the percentage of meander evolution that had been recorded for plot B. For the first 61 years, the percentage of meander change in plot B was 0 % for Ub1, Ub2, Ub3, Ub8, and Ub9. However, a considerable meander change of permanent place in the subplot Ub6 and Ub5 recorded a percentage of 16.5 and 19 %, respectively. This was because the subplot Ub6 and Ub5 experienced the development of settlements, and the Kuala Tahan town, Pahang, had gone through urbanization process. However, the evolution of land use of this

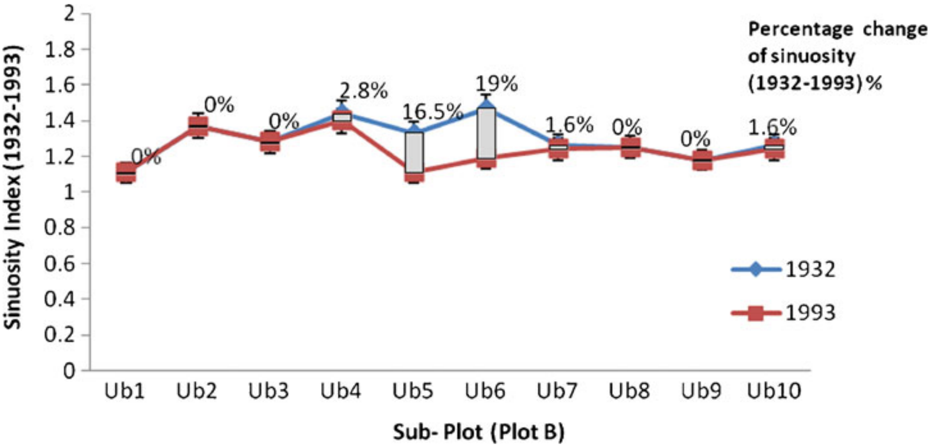

Fig. 8 Percentage of meander evolution for plot B from 1932 to 1993

area was not going drastically over the plot A's area (Fig. 5). For soil characteristics, this area (after Ub4 to Ub10) with *red and yellow latosols and red and yellow podzolic soils* were similar with all plot A soil characteristics. Therefore, it was not surprising to discover that the meander changes begin to occur in this area.

For the total rainfall pattern, Fig. 9 illustrates the total rainfall pattern for plot A and B. On the limitations of the data for the year 1932, this study adopted the total rainfall data from the Department of Irrigation and Drainage Malaysia (DID) from the years 1980–1994 to see the trend of the total rainfall in plot A on DID rainfall station 4122067 and plot B on DID rainfall station 4123116 where the total rainfall in plot A was higher than in plot B, for instance, the highest total rainfall recorded at plot A was 2,760 mm on 1993 and plot B was 2,543 mm on 1991 (Fig. 9). These data showed an impact on global climate change that had led to an increase in the amount of rainfall in these areas. The large-scale of the land use change without mitigation at plot A exacerbated the channel geometry and river plan change in this area.

Generally, the result implies that there were highly significant differences in the evolution of both river alignments in the upper reaches of the Pahang River. Although both plots were the main alignment of the same river, they showed vastly different evolution. This phenomenon was due to two main factors: human activities and natural changes. The large-scale of human activities were among the main causes of the occurred meander evolution. Based on Fig. 10, the amount of evolution that occurs for plot A (impact of human activities) was 86.7 % compared with 41.5 % in the plot B area. Therefore, the human activities without mitigation are very dangerous for the river and natural environment's health (Armas et al. 2013).

4 Conclusion

This article has considered the patterns, modes, types, and rates of river channel change in the Pahang River as representing the selected study research. Overall, the evolution of meanders that occurred in the upstream of the Pahang River for 61 years (1932 to 1993) was quite

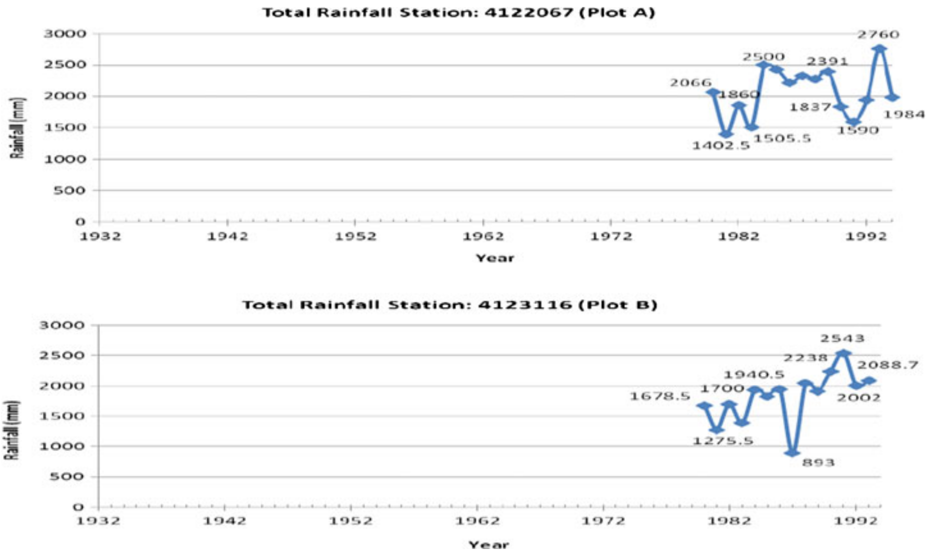

Fig. 9 Total rainfall pattern for plot A and B from 1980 to 1994

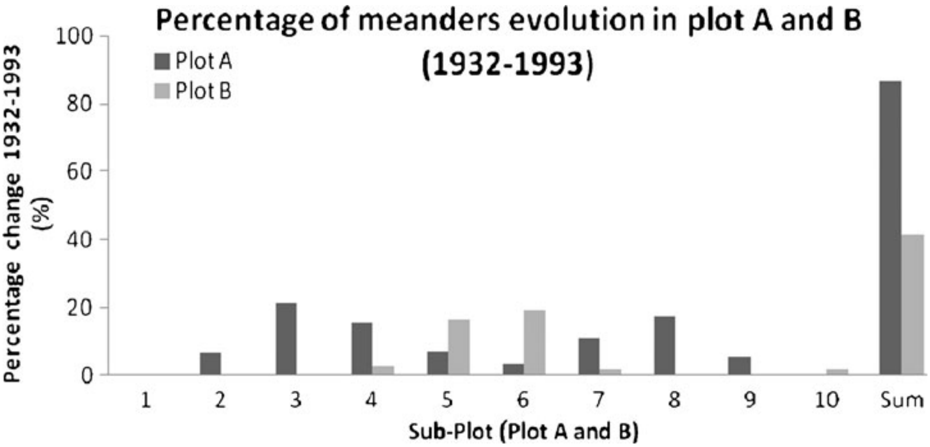

Fig. 10 The percentage of the meanders evolution difference in plot A and B

significant especially for plot A against plot B. The study of meander evolution was also successful in identifying the early stages of root problems. These changes also posed

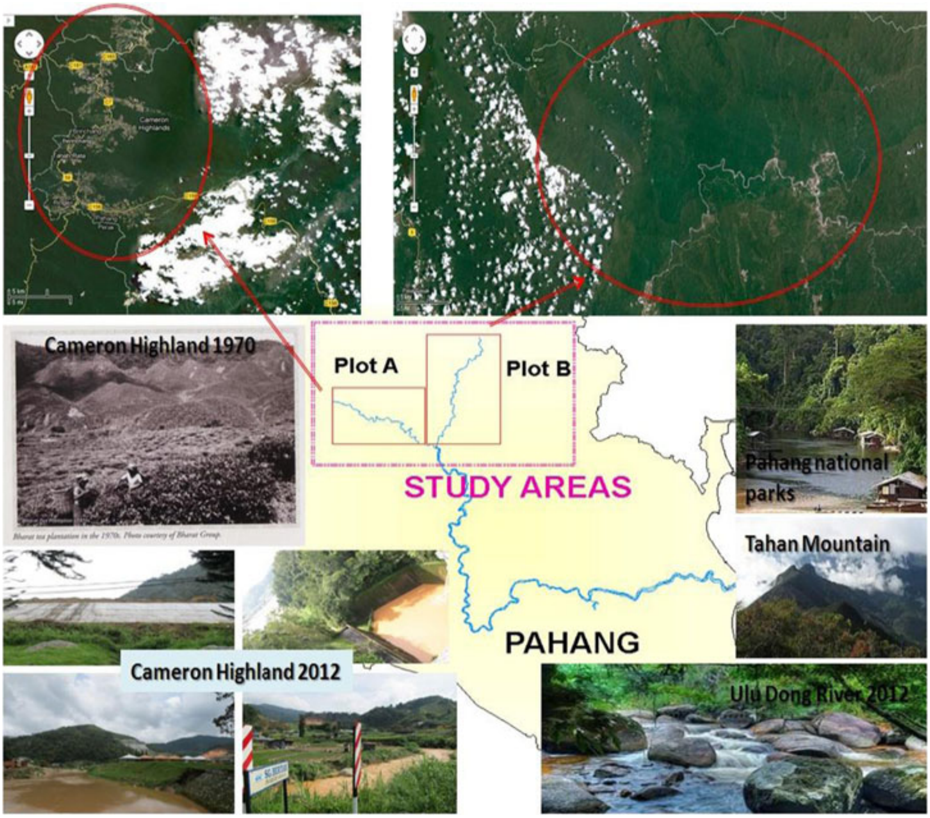

Fig. 11 Difference in general land use of plot A and plot B

significant impact on the physical environment, particularly for the Pahang River that has a bigger downstream. The problems of flood, erosion, sedimentation, water quality, and so on can be well identified if they have been studied in a more specific and focused manner.

The impact of human activities produced the large-scale of open area in the Cameron Highlands with global climate change detected as the primary cause of significant changes to the meander changes in plot A. While for plot B, the reserved forest areas were the cause of meander evolution that occurred slowly and naturally (see Figs. 5 and 11). The evolution of meanders are drastic as it also served as the indicator of ecosystem change for the basin. This will cause multiple problems for major rivers' alignment such as erosion, sedimentation, and flood. Therefore, control of large-scale deforestation without mitigation should be emphasized to prevent any serious problems in future.

Therefore, the study proposes some suggestions to mitigate or adaptation strategies to cope with global changes for the future such as regulate the land use change development by providing some mitigation measures such as tightening the laws of the Environmental Impact Assessment (EIA) rules; banning the large-scale deforestation at highland areas; establishing buffer zone areas for deforestation and restricted zones for the main river (500 m to river banks); monitoring and applying the development of the river erosion control; and establishing the applications of sediment management to all types of development, such as sediment traps, sediments pond, and others.

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