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Modeling of 1D sediment transport in the langat river using quasi-unsteady HEC-RAS

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Abstract: The primary goal of this research was to investigate the sediment transport characteristics of the Langat River. The Langat River is situated in the state of Selangor, Malaysia, and is prone to flooding on a regular basis. The River Analysis System tool from the Hydraulic Engineering Center (HEC-RAS) was used to determine sediment transport capacity of the river. The sediment transport and hydraulic models were created using elevation and cross-sectional data in HEC-RAS. The sediment transport model employed several approaches to calculate sediment transport capacity. HEC-RAS contains some useful built-in functions which were used in this study to visualize the sediment transport, calibration and calculation of Manning's roughness coefficients, and forecast changes in bed elevation. The investigation reveals that urban development has resulted in a large rise in riverbed depth, implying that is no difference in flooding pattern in the short period of time. This paper focuses only on bed load sediment. The results of three years of stream flow show that some areas have experienced silt transport and river deposition. The river had changed slightly after utilizing the Laursen-Copeland method in HEC-RAS. The simulation outcome shows the segment that experienced sediment transport at River Stations RS 12926 from Lui, RS 9362 from Langat upper reach, and RS 3730 from Langat Lower Reach are experiencing sediment deposition activities.

Keywords: HEC-RAS, Sediment, Sediment transport, Deposition

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1 Introduction

Eroded sediments can be found in any of three forms in rivers that transport water: bed load, suspended load, or wash load. Rivers are subjected to significant deposition and bank erosion due to natural and anthropogenic forces (Simons and Şentürk, 1992). Depending on the location and hydrological regime, the effects of erosion and deposition can cause significant changes in river geomorphology in long-term. The conveyance of silt alters the river reach's capacity. Siltation and navigation issues in rivers are caused by increased soil erosion. Several factors influence sediment transport in rivers, including particle size and type of sediment, drainage area size, vegetation and land usage, river basin, climate change behavior and temperature, flood occurrence, and land slope.

Sediment is one of the most important variables affecting the morphology of rivers in Malaysia. One of the key problems of hydraulic structure constructions (i.e., dam, irrigation canal), or the use of river for navigation purposes is the physical characteristics of sediment delivered within reach. As Langat River is used for navigation purposes, the riverbed built-up that has resulted in shallow depth may have an impact on its use. To alleviate the problems caused by changes in river morphology, it is necessary to examine sediment flow and riverbed features. The river reach is chosen depending on the available gauged stations and the settlement's proximity. The hydraulic analysis of the sediment transport model was developed using HEC-RAS in this study. The geometric data were created in ArcGIS using the HEC-GeoRAS extension from a 30 m × 30 m meter resolution digital elevation model. Two sediment transport functions (e.g., Laursen and Rubey methods) and Manning's roughness coefficients were used for model calibration and validation. The output of the model shows the change pattern of riverbed and river reach subjected to erosion or deposition. The output of the model can serve as a guide for the relevant authorities to mitigate the sediment-related problem.

Numerical models (from one-to-three dimensional) have been established in recent years to reproduce realistic processes. One-dimensional model is preferred by many due to its simplicity that leads to shorter computations and calibration time, a reduced amount hydrologic data for model evaluation (Horritt and Bates, 2002). Changes in streamflow have an impact on the amount of silt transported downstream and the severity of water shortages (Pitlick and Wilcock, 2001). Climate variability corresponds to streamflow variability, which enhances the hydrological cycle's uncertainty (Lee et al., 2018). According to Kalra et al. (2017), the timing of the peak flow varies due to variabilities. HEC-RAS is a powerful hydraulic modelling tool for runoff simulation based on river characteristics (Abdessamed and Abderrazak, 2019). Despite the uncertainty of extreme occurrences, its 2D numerical analysis is effective for flood modelling (de Arruda Gomes et al., 2021).

2 Materials and Methods

2. 1. Study area

With the expansion of Putrajaya, which is the administrative and judicial capitals of

Malaysia, the upper part of the Langat River has been designated as a study area and has recently become a key source of sand for buildings. The Langat River basin is located in the south and southeast of the state of Selangor, as well as minor areas of Negeri Sembilan and Kuala Lumpur. The basin is bordered on the east by the Main Range Titiwangsa and on the west by the Straits of Malacca. The basin's geography is varied, ranging from mountainous areas in the northeast to lowland areas in the centre and lowlands in the south-west. The river system runs through the three states of Malaysia, i.e. Selangor, Negeri Sembilan, and Putrajaya. The total length of Langat River is about 180 km and its river basin covers 2,350 km^2 and has a mean annual discharge of 35 m^3/s, with a mean annual flood of 300 m^3/s (Ghani et al., 2011). The Langat River is used for a variety of activities other than water delivery, including recreation, fishing, waste disposal, irrigation, and sand mining.

2. 2. Methodology

To accurately replicate the sediment transportation of a particular river reach, the HEC-RAS 5.0.1 was fed with precise input data of Digital Elevation Model (DEM), discharge, gauge height, sediment/sediment load series, and temperature. One-dimensional hydraulic model was used to generate the water surface profiles, including sediment aggradation, riverbed depth analysis, and erosion. Quasi-unsteady flow data was used to simulate sediment transport. The processes for pre-processing data and preparing the computational domain were defined by the general approach to numerical modelling. The simulation's result was determined by post-processing the acquired data by running the model and visualizing the results. Three categories input data were used as simulation input: geometric data (as per Table 1), quasi-unsteady flow data, as well as sediment data. The boundary conditions for the simulation as stated in Table 1.

Table 1. Observation field data for Langat River (Ghani et al., 2011).

Study area	**Study area Langat River**
Q (m^3/s)	2.75-120.76
V (m/s)	0.23-1.01
B (m)	16.4-37.6
Y_o (m)	0.64-5.77
A(m^2)	8.17-153.57
R (m)	0.45-3.68
S_o	0.00065-0.00185
d_{50} (mm)	0.31-3.00
Manning n	0.034-0.195

A DEM, which defines the height of any specific point within a given geographical boundary was used to establish the topography of the study area in 3D. The DEM with a resolution of 30 m × 30 m was obtained from the Shuttle Radar Topography Mission (SRTM). DEM for the research region was masked with ArcGIS 10.2's geo-processing extension topographic factors such as basin shape, stream network flow direction, etc. were extracted to produce geometric data such as stream centerlines, flow paths, and bank lines; reshaping was done when needed, and the attributes were grouped in HEC-GeoRAS. After completing the layer setup, the stream centerline attribute was filled in. RAS Geometry was used to populate the cross-section cut lines property, which was digitized as shown in Figure 1. Then, for the RAS GIS Import File, all these files were created.

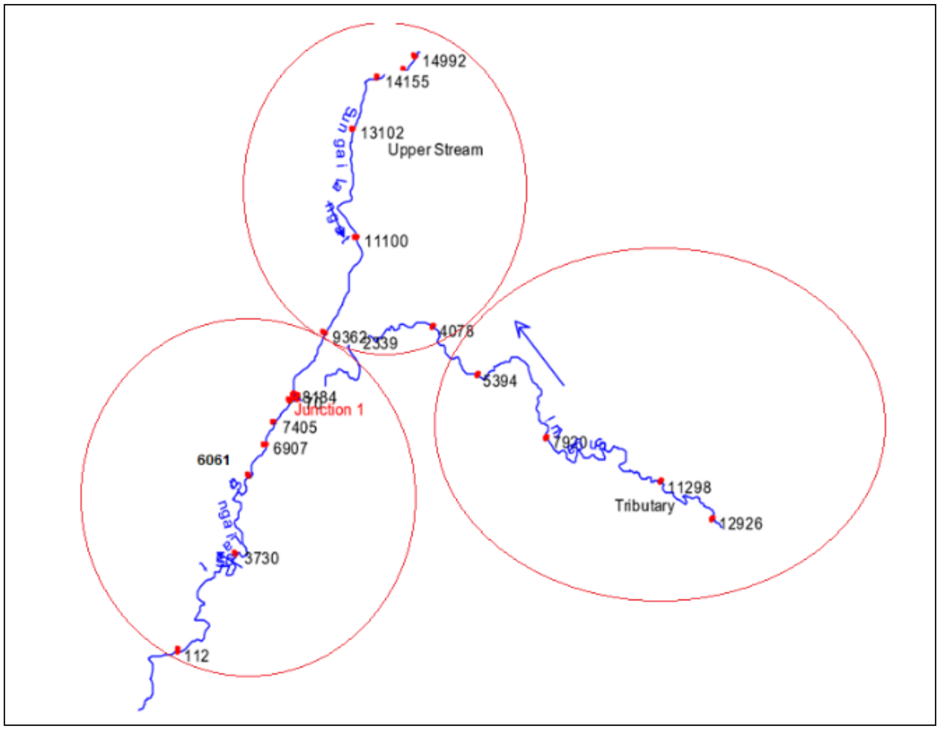

Figure 1: LRB upstream, downstream, and tributary with bank points.

Sediment data boundary conditions used were Sediment Load Series for both Lui River and Langat River upper reach river stations. The sediment transport computation equation used in Laursen-Copeland method (Mohammed et al., 2018) is shown below. Likewise, fall velocity computational equation used in the Rubey method (Molinas and Wu, 2001) of HEC-RAS is also utilized for the simulation of the sediment model and is explained below.

$$C_m = 0.01\gamma\left(\frac{d_s}{D}\right)^{\frac{7}{6}}\left(\frac{\tau_0'}{\tau_w} - 1\right)f\left(\frac{u_0}{\omega}\right)$$

where: `
C_m = concentration of the sediment discharged (tonnes/day)
γ = unit weight of the water
d_s = Mean particle diameter
D = mean particle diameter
τ_0' = bed shear stress due to grain resistance
τ_w = critical bed shear stress
ω = particle fall velocity (m/s)

u_0 = shear velocity (m/s)

Laursen method predicts the total sediment load value. The applicable particle size used for this formula is within a range of 0.011 mm to 29 mm (Hamzah, 2014). Hence it is feasible to be used for this project. The equations to be used for the Rubey method of Fall Velocity are as follows:

$$\omega = F_1\sqrt{(s-1)gd}$$

$$F_1 = \sqrt{\frac{2}{3}+\frac{36\nu^2}{gd^3(s-1)}} - \sqrt{\frac{36\nu^2}{gd^3(s-1)}}$$

where:

ν = Kinematic viscosity

s = Specific gravity of particles

d = Particle diameter

g = Gravitational acceleration (m/s^2)

3 Results and Discussions

The HEC-RAS model was calibrated using the automated Manning’s value. The initial values entered, will be a placeholder for the automated routine to start from. The manning’s value chosen for the Langat River Basin is 0.035.

3. 1. Annual sediment load observation for year 2015, 2016, 2017

Figure 2 shows of the sediment load discharge (kilotons/day) plotted against time to observe the changes of the riverbed throughout the research duration. It can be observed that the highest cumulative annual sediment load was recorded in the year 2015. This amounts to a total of 20957.39 tons per day of transported load of sediment. It can also be seen that the sediment load transported has gradually decreased over the years of 2015 to 2017. The highest value was found in the Langat River Basin (LRB) Lower Stream (LS). The lowest sediment load value observed was 948.98 tons per day in year 2017 in Lui.

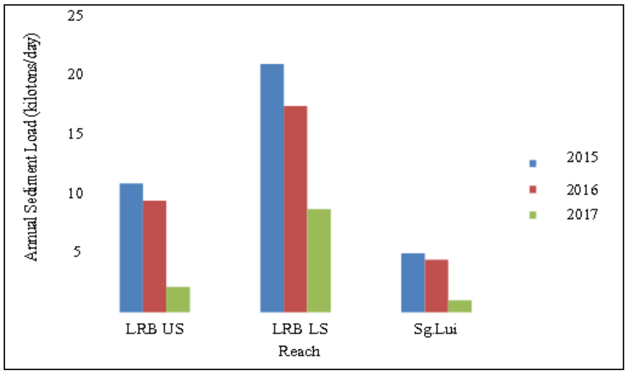

Figure 2: Annual sediment load (kilotons/day) for 3 reaches of LRB.

3. 2. Critical bed-changes and erosion level found in the sediment output of the river reaches

The critically affected areas of the riverbed due to sediment transportation were analyzed based on the output of HEC-RAS, showing the changes which occurred in river profile and cross-section for each reach of upper LRB. The changes were compared for both dry (SW monsoon) and wet (NE monsoon) seasons separately to observe the level of erosion and deposition of sediments occurring in the river cross sections. For this comparison, River Station, RS 12926 from Lui, RS 9362 from Langat upper reach, and RS 3730 from Langat Lower reach were used as they showed the largest changes in the channel bed elevation. These bed changes can be better understood by observing the results as shown in Figures 3 to 5. The results conclude that the erosion level or degradation of channel bed was the highest in the year 2016. Followed by 2015 and 2017. Figure 3 depicts an increase in the levels of the riverbed throughout the 2015 to 2017 duration. While the increase in elevation of riverbed was 0.14 m in 2016, the riverbed appears to have a deposition of sediments. The deposition in 2015 is observed as the second highest with a 0.11 m increase in elevation. It is clearly shown that the lowest value was obtained for 2017.

On the other hand, Figure 4 shows the changes occurring in cross-sectional elevation of the river over a period of 3 years for the RS 9362 of Langat. This is the upper reach of Langat River, connecting to the downstream through a junction. Results concluded that the erosion level or degradation of channel bed was the highest in the year 2016. Followed by 2015 and 2017. It also shows an increase in the levels of the riverbed throughout the 3 years for RS 9362 of the upstream LRB of upper reach. The largest increase in elevation of riverbed was 0.15 m in 2016 with a deposition of sediments. The deposition in 2015 is observed as the second highest with a 0.12 m increase in elevation. It is clearly shown that the lowest value was obtained as 0.09 m deposition for 2017.

The RS 9362 of Langat is the upper reach of Langat River, connecting the downstream through a junction. Results concluded that the erosion level or degradation of channel bed was the highest in the year 2016. Followed by 2015 and 2017. Figure 5 shows an increase in the levels of the riverbed throughout the 3 years for RS 3730 of the downstream LRB of lower reach. Hence, showing a negative erosion level. The largest increase in elevation of riverbed was 1.2 m in 2016 with a deposition of sediments. The deposition in 2015 is observed as the second highest with a 0.8 m increase in elevation. It is clearly shown that the lowest value was obtained as 0.15 m deposition for 2017. The values for bed change in RS 3730 of lower river reach appear to be highest among the other river reaches for SW monsoon. Meanwhile the values for bed change in RS 12926 of Lui reach is observed as the lowest.

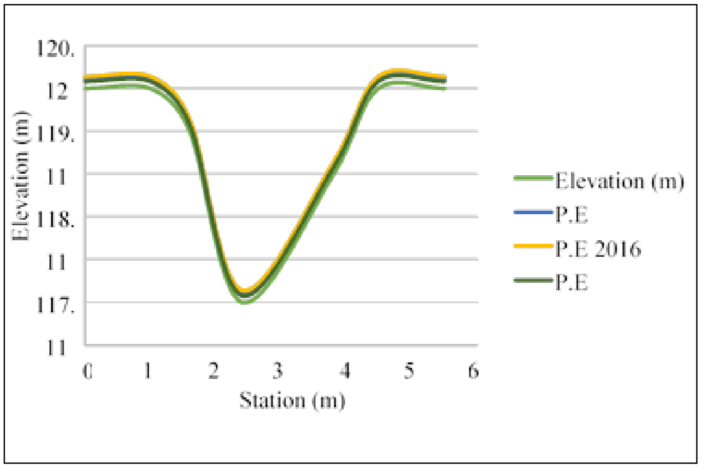

Figure 3: Potential erosion at LRB tributary, RS 12926, Lui.

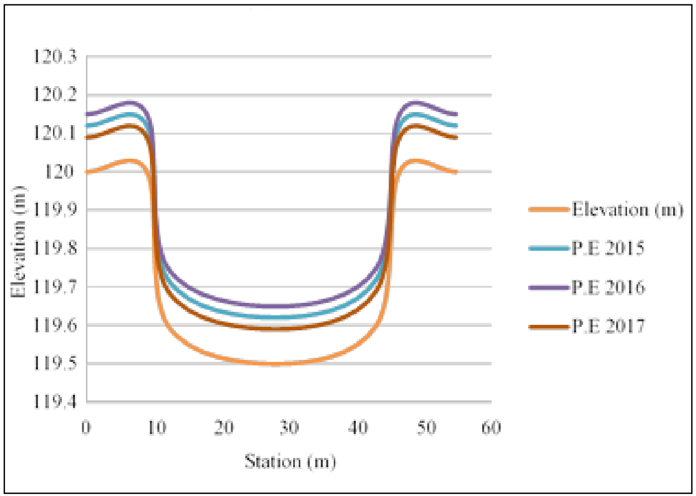

Figure 4: Potential erosion at LRB upstream, RS 9362, upper reach.

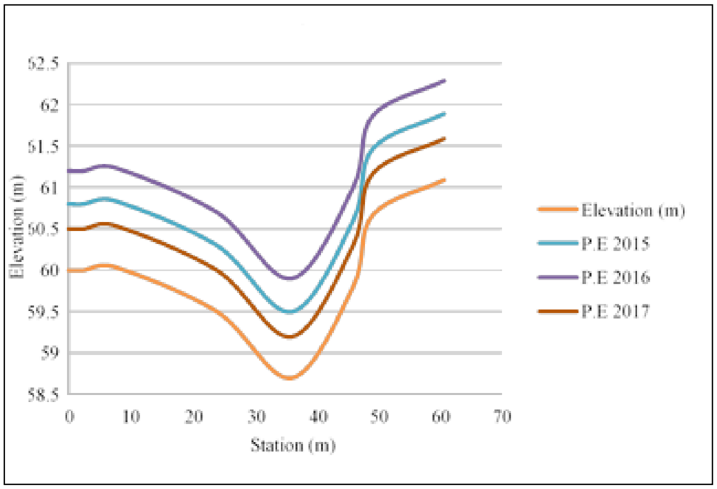

Figure 5: Elevation and potential erosion (P.E) of RS 3730, lower reach.

4 Conclusion

The HEC-RAS model, along with RAS Mapper, is used in the sediment transport analysis. Sediment load analysis is discussed by showing the relationship between sediment load and time for each river reach. Seasonal trend analysis of the river reaches shows that the SW monsoon duration showed less sediment load compared to the NE monsoon. The lower reach of LRB showed the highest value during the month of October, with a value of 166700 tons/month sediment load in 2016. Critical area identification results show a higher chance of the upper reach of the LRB undergoing erosion and the lower reach of the LRB undergoing deposition. Deposition occurs in the NE monsoon season when the rainfall and river flow are relatively high. Since the upstream areas face a higher river flow, they are more prone to erosion of the riverbed level. Erosion is more prone to occurring in the SW monsoon season or dry season when river flow is low due to low rainfall. Hence, the sediment particles will settle and form a deposit on the riverbed. Overall observation depicts that RS 12926, RS 9362, and RS 3730 are the critical river stations that reported deposition during the monsoon season.

The erosion and deposition trend of the riverbed must be considered before constructing any hydraulic construction. The sediment transport model by HEC-RAS presented in this work depicts the movement of sediment transport in terms of erosion and deposition in Langat River Basin. The sediment transport capacity estimated by this model is useful for river management in long-term. The results of bed load and sediment load changes in the river cross-sections can aid in the development of a more robust model for predicting future sedimentation scenarios.

This study is vital in determining the capacity of Langat River reach, as well as the nature of the river and its physical properties, which can assist the relevant authorities in river management. Stream bank stabilization could be one of the most effective ways to reduce erosion rates while simultaneously benefiting aquatic habitats such as fish, plants, and macroinvertebrates.

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Conflict of interests

The authors state that there are no conflicts of interest regarding the publication of this article.

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