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ASSESSMENT OF SEDIMENT REPLENISHMENT VOLUME IN LANGAT RIVER SYSTEM

Nur Hidayah Huqmah Mahmud[1a], Nor Rohaizah Jamil[2a*], Ahmad Fikri Abdullah[3b], Mohd Sofiyan Sulaiman[4c]

[a]Department of Environmental Science, Faculty of Environmental Studies,Universiti Putra Malaysia, 43400 Seri Kembangan, Selangor, MALAYSIA. Email: hidayahuqmah@gmail.com[1]; norrohaizah@upm.edu.my[2]
[b]Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400 Seri Kembangan, Selangor, MALAYSIA. Email: ahmadfikri@upm.edu.my[3]
[c]Faculty of Ocean Engineering Technology and Informatics, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, MALAYSIA. Email: sofiyan@umt.edu.my[4]
Corresponding Author: norrohaizah@upm.edu.my
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ABSTRACT The river sand mining activity has taken place in a sand-bed river system in Selangor, Malaysia for decades even before the legalisation was initiated in 2008. This study focuses on the determination of optimum sand extraction for low-flow and high-flow seasons. The sand replenishment rate was used as the benchmark in determining the threshold level of the extractable rate in the Langat River, Selangor system. The total sediment load was computed using Yang (1973) equation due to the high percentage of agreement between the predicted sediment load and measured sediment load. Almost 41.6% of the predicted data fall within the allowable discrepancy ratio test between the predicted value and measured value. The comparison of sand replenishment rate in high and low flow seasons proved that the river system has quicker capabilities in sand replenishment rate at the extraction point during the high-flow season compared to the latter by 83%. The quantifiable volume of the extractable sand rate is proposed specifically during low-flow months (May to September) whereby the slower replenishment rate is critical and riskier. The optimal sand mining volume during the low-flow months is calculated by reducing 10% from the total replenishment volume and the recommended optimum extraction load has been delivered by the number of 25 tons lorries for easier observation by the contractor and authority's body. The monthly optimum extraction in Langat River during low-flow months is calculated at a minimum of 437 trucks to a maximum of 20,114 trucks per month.

Keywords: Hydraulic, river system, sediment replenishment volume, sediment transport.

1. INTRODUCTION

The non-metallic mineral industry is part of the highest contributor to the manufacturing sector in Malaysia (Ashraf et al., 2012). The non-metallic mineral is also known as industrial minerals such as sand and gravel, clay and limestone. In order to meet the industrial demands, sand mining production has increased by about 15% in 2015 with a monetary value of approximately RM100 million (Department of Minerals and Geoscience Malaysia, 2014). In Malaysia, sand resources mainly come from rivers, alluvium and coastal areas.

The contribution of sand and gravel in economic growth enables alleviating the occurrence of over-extraction. The environmental impacts from river sand mining have been addressed in early studies from the developed country (Dunne et al., 1978; Follman, 1980; Kondolf, 1994, 1997) and followed by other studies that include developing countries such as Nguyen (Nguyen and Phuong Le, 2015) in Vietnam, Wu and Lu (Wu et al., 2007; Lu et al., 2007) in China, and Mattamana (Mattamana et al., 2013) in India. The concern of excessive mining activity is that it will eventually interrupt the bedload transportation in the river that would cause riverbed erosion and riverbed stability-instability (Kondolf et al., 2002; Mmom et al., 2012). The excessive unplanned river mining activity has contributed to the riverbed degradation and changing in replenishment rate towards the river downstream. (Ariffin et al., 2002; Collins et al., 2011).

Based on the fundamentals of hydraulic, river flow has the ability to transport the debris as the resisting force is exerted on the water (Leopold et al., 1953). Alongside, the downstream of the river is based on the gravitational force acting as an inducing force while the friction resistance helps in the degrading process of the channel (Kondolf et al., 2002; Ra et al., 2012; Rosgen, 1994).

The sediment transportation is positively influenced by the grain size (Engelud et al., 1976; Hafifi et al., 2015; Julien, 2002) as the movement is influenced by the unstable turbulence at the bed of the channel (Sharma et al., 2021). An in-depth discussion was made by Sulaiman et al. (2017) to illustrate the differences between the mechanics of sediment transport at lowland and highland river systems. The dynamics of transport processes has explained the Shields number parameterisation due to uniform particle size at the river bed. Several published studies in Langat River focus on sediment transport and provided a significant impact on river physical parameters (Kiat et al., 2005; Memarian et al., 2012). Alternatively, human activity that took place in the watershed area that enhances the sediment distribution across the river has not been studied adequately (Peck et al., 2013) Langat watershed has undergone rapid development in the form of urbanisation and industrialisation (Mohamed et al., 2009).

The evaluation of sediment transport and replenishment volume is important in Sungai Langat for appropriate management and policy implementation especially by the local government units within the Langat watershed. This study focuses on the assessment of sediment replenishment volume to calculate the prediction of the optimum volume of sand extraction at Langat River, Selangor, Malaysia from 2016 to 2017. The main objective of this study is to determine the optimum amount of sand mining of Langat River, supported by the specific objectives in identifying the particle size in the river and determination of the sediment transport during the low flow season.

2. MATERIALS AND METHODS

2.1.1 Description of the study area

The data from Pourebrahim (2015) revealed that the forest area shrunk from 41.7% in 1974 to 8.08% in 2010 while the developed area increased from 0.51% to 10.04% in the same years. The agricultural sector was the most beneficial of all sectors that keep increasing from 51.85% to 76.89% in the aforementioned years. Should this trend continue, the forest area would have reduced to 3.73% in 2025

Based on the study objective, twelve sampling stations have been identified as monitoring points within the study area (Figure1 and Table 1). The stations have been selected based on the active sand mining activity, the past sand mining area and the control station. Two control stations are located in the main river while another one point is located in Beranang River. Three control stations were used to represent the river reaches with no sand extraction activity, thus reflecting the natural morphological characteristics without any man-driven alteration. It will be used as a station, which represents the undisturbed condition for comparison purpose with the disturbed stations.

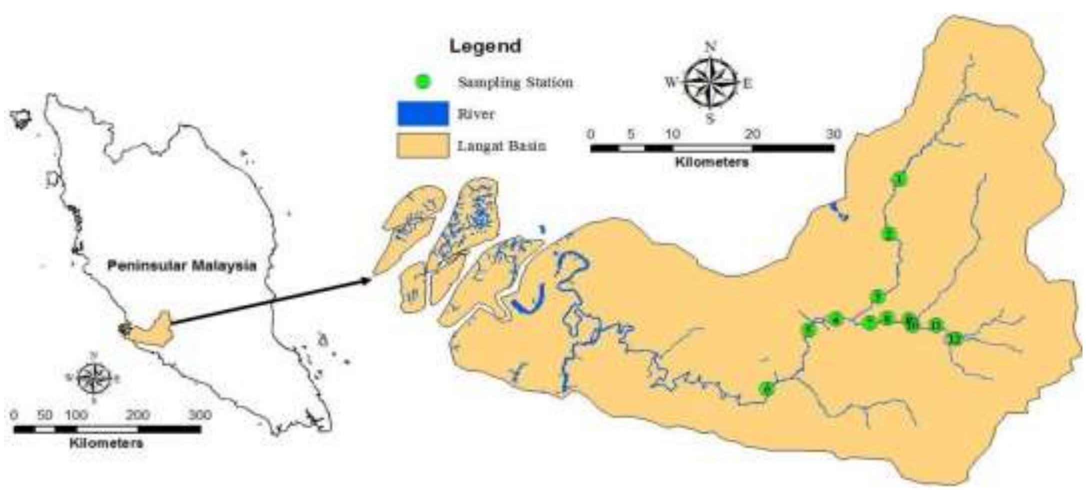


Figure 1: Geographic location of the study area in Langat River Basin, Malaysia along with sampling points.

Table 1: The sampling station in Langat River.

Sampling stations	Station No.	N	E	MSL Elevation (m)	Remarks
Hulu Langat	1	3.09767	101.80682	48	Mining Point
Kajang	2	3.00047	101.77602	40	Mining Point
Teras Jernang	3	2.93468	101.77994	23	Control Point
UKM	4	2.87176	101.85023	19	Mining Point
Dengkil	5	2.88863	101.82915	15	Mining Point
Bukit Changgang	6	2.88865	101.80868	12	Mining Point
Semenyih River (pt. 1)	7	2.88863	101.80227	19	Mining Point
Semenyih River (pt. 2)	8	2.89672	101.77417	21	Mining Point

Semenyih River (pt. 3)	9	2.89108	101.75478	23	Mining Point
Beranang River (pt. 1)	10	2.89557	101.71703	23	Mining Point
Beranang River (pt. 2)	11	2.88264	101.68687	24	Control Point
Beranang River (pt. 3)	12	2.79239	101.63272	23	Mining Point

2.2 Physical parameter of Langat River

The sediment transport rate, Q_s is used to calculate the actual sediment load at a selected cross-sectional reach. The sediment discharge or sediment transport rate is being used to represent the ability of sediment material to move per unit time. The physical parameter of the river such as channel width (W); total cross-sectional area (A); min-max velocity (V), water discharge (Q) and Total Dissolved Solid (TDS) have been measured in-situ based on one water cycle (low-flow and high-flow) (Tables 2 and Table 3). The complete water cycles obtained from the mean of 35 years of rainfall data from the JPS station along the Langat River have been divided into four months for each season annually in accordance with the Malaysian climate. The sampling period is based on flow regimes, either at low, moderate or high-flow. Based on the flow regimes, the characteristic of the season is also referred to according to seasonal periods which are known as dry, normal and high season. The high-flow sampling period was completed from December 2015 to February 2016 and the low-flow sampling from May to June 2016.

The use of field data is crucial to validate the predicted model for sediment load computation (Yang et al., 2006). Prior to sediment load computation, river gauging was commenced at each station to obtain the cross-sectional area, river width, river velocity and river discharge. These hydraulic geometry data were manually obtained for both low-flow and high-flow season as shown in Table 2 and 3 respectively.

Table 2: Field data for Langat River during the low-flow season.

Station No.	**Channel width W (m)**	**Total cross-sectional area A (m^2)**	**Min-max velocity V (m/s)**	**Water discharge Q (m/s)**
1	30	29.1	0.07-0.21	2.91
2	18	28.8	0.07-0.68	6.56
3	23	32.8	0.04-0.48	6.62
4	25	25.8	0.01-0.09	1.03
5	42	22.75	0.61-0.75	11.15
6	35	86	0.12-0.93	27.52
7	35	24.5	0.21-0.76	7.42
8	21	54	0.11-0.27	6.48
9	23	37.2	0.09-0.29	5.58
10	12	7.8	0.62-0.98	4.6
11	20	33.2	0.13-0.57	8.02
12	10	66.8	0.06-0.52	8.3

Table 3. Field data for Langat River during high-flow season.

Station No.	Channel width W (m)	Total cross-sectional area A (m^2)	Min-max velocity V (m/s)	Water discharge Q (m/s)
1	36	48.9	0.08-0.74	13.69
2	18	28.2	0.21-0.62	8.18
3	22	35	0.45-0.87	6.32
4	16	10.72	0.18-0.78	20.65
5	40	101	0.22-1.18	48.31
6	40	91.15	0.13-1.28	50.5
7	35	79.95	0.08-0.47	15.19
8	22	35	0.23-1.21	20.3
9	22	40.2	0.12-0.84	12.06
10	14	11.85	0.22-0.98	6.28
11	22	34.2	0.15-0.76	14.76
12	14	32.8	0.24-1.18	9.58

2.3 Sediment Transport Rate

The bed load sample has been taken from the upstream towards the downstream. Three samples were taken at every station of sampling point by using the Van Veen grab sampler. The samples were left to dry for 24 hours prior to obtaining the bed material classification. The sieve diameters used are 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, 0.063mm and 0.01mm. The method is the most usual and convenient method for particle size distribution analysis and the result is represented as a cumulative distribution curve.

The grain-size distribution changes determined the transport of the sediment and sedimentation in the river towards downstream (Collins et al., 2011; Hafifi et al., 2015; Pike et al., 2010) and fall velocity of sediment particle (Abidin et al., 2017; Ashraf et al. 2011). Actual bed load values (see Table 4) were measured using the Halley-Smith bed load sampler having a nozzle width of 100 mm x 100 mm. The time taken to fill in the bed load sample into the device is set to 30 minutes. The fill-in volume is less than 70% of the total trap capacity which alleviates the errors of 'over-occupied' that may hinder device accuracy.

$$T_j = \sum_{1}^{n} G_b \tag{1}$$

$$G_b = \frac{W_i}{(T * h_s)} xb \tag{2}$$

The total bed load rate can be calculated using Eq. 1 and Eq. 2. Where T_j= rate of bed load rate for the predefined cross-section in kilogram per second, G_b = rate of bed load rate for each section within the predefined cross-section in kilogram per second, b=ratio between channel width (B) and the number of section within cross-section (n), W_i=weight of bed load sample in kilogram, T= duration of sampling in second, h_s= nozzle width in meter.

In the calculation of the sand replenishment rate of the river, there is a recommendation from a previous study stating that the Yang equation was suggested for the natural river (Fang et al., 2017) while the Engelude-Hansen equation is for the subcritical river (Engelund et al., 1967). Langat River is considered as a natural river where 15% of Langat catchment is covered with forestry and less than 20% of river diversion have taken over. Therefore, the Yang equation has been chosen to predict the sediment transport rate outside the observation data range as recommended for the sand-bed river (Asyraf et al., 2011). The sediment transport rate equations that have been used to estimate the sediment replenishment rate (Q_j) for each station is Yang (1973) equation. The equation recommended for sediment transport based on stream power unit as Eq. 3.

$$log\ C_t = \frac{5.435 - 0.286\ log\ log\ (W_S d_{50})}{\upsilon} - \frac{0.4571\ log\ log\ U_*}{W_S} + \left\{ \left(1.799 - \frac{0409\ log\ log\ (W_S d_{50})}{\upsilon} - 0.314\ log\ log\ \frac{U_*}{W_S} \right) \times log\ log\ \left(\frac{V S_O}{W_S} - \frac{V_C S_O}{W_S} \right) \right\} \tag{3}$$

Where C_T is the total sand concentration in parts per million is, W_s is terminal fall velocity in meter per second, is the average particle diameter of granular material in millimetre, υ is kinematic viscosity in meter cube per second, U_* is the shear velocity in meter per second. The Q_j estimation is based on the surveyed data during high flow and low flow season and the interpolation of data by using Manning's equation by Robert Manning, 1889. Eq. 4 is based on the average flow of the channel to the energy loss.

$$Q_j = \left(\frac{1}{n}\right) A R^{\frac{2}{3}} \sqrt{S} \tag{4}$$

Where, Q_j is the flow rate in meter cube per second, *n* is Manning's roughness coefficient, *A* is flow area in meter square, *R* is the hydraulic radius in m, and *S* is channel slope. The flow-frequency distribution curves were used to analyse the flow value related to the principal transport of sediment.

The sand replenishment volume was predicted based on 25-ARI flood discharges with 10 days flood assumption. The extraction has been recommended not more than the site-specific sand replenishment rate (Ashraf, 2011). The calculation of sediment replenishment volume is adapted from the River Sand Mining Management Guidelines (2009). The extraction volume determination is based on the flow discharge to calculate the sediment discharge, Q_j by using Yang (1974) equation. The prediction of Q_j obtained from the sediment rating curve is shown in Figure 2. The replenishment volume was determined by a 5-month dry period. The extraction has been recommended not to exceed the site-specific sand replenishment rate. The estimation of the optimum extractable volume of the sand has been produced based on a 10% reduction of the replenishment rate of each point.

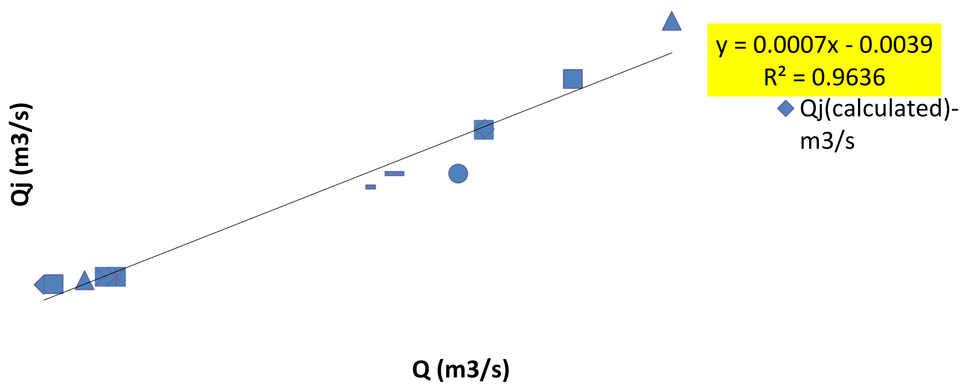


Figure 2: Example of sediment rating curve determination at Station 2 (Kajang)

The recorded 25-ARI flood (from DID rainfall Station Kajang) determine the high flow at 540 m^3/s for 10 days. The extraction volume determination from the linear equation of the sediment rating curve calculated the Q_j

25-year ARI = 540 m³/s

For flow discharge	=	540 m^3/s	
Q_j	=	$M(540\ m^3/s) - C$	(5)

Assuming a 10-day flood,

Total Replenishment volume	=	Q_j *10 * 60 * 60 * 24**(A)**	(6)

Annual sand replenishment volume (ton) *based on 25-ARI	**(A)*2.41** = **(B)**
Total optimum extractable sand (10% less) for 5 dry months (ton)* dry months = May to September	**[(B)-(B*10%)]/5** = **(C)**
Monthly optimum extraction load*1 truck = 25 ton	**(C)*25** = Number of trucks

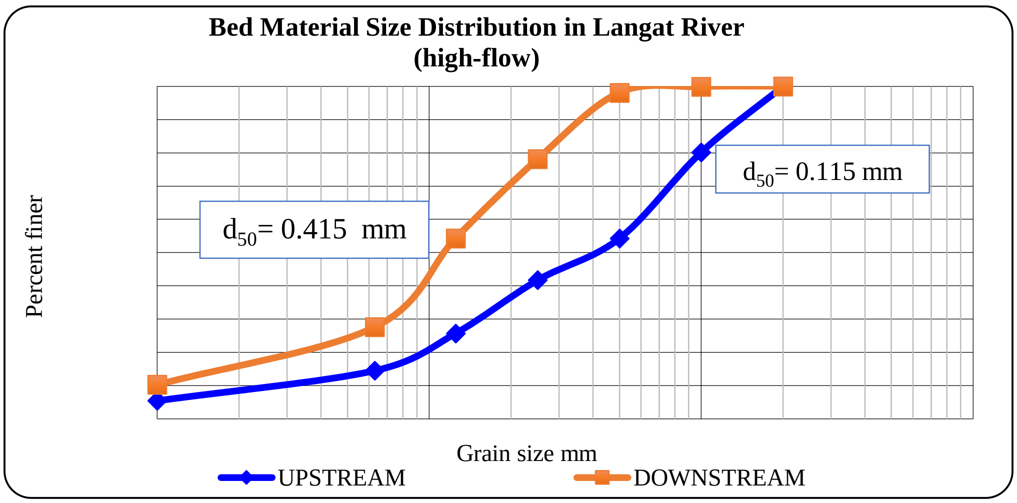
The recommended optimum extraction load has been delivered by the number of lorries (25 tons) for easier observation by the contractor and authority's body in order to keep the river stable. Station 1 until Station 6 represents the main Langat River while the rest is from Langat River tributaries, Beranang River and Semenyih River.

The upstream of Langat River, Station 1 and Station 2 shows that the monthly extraction during the 5 months dry period is approximately in the same range. The main river resulted in lower optimum sand extraction volume compared to the tributaries, as the water discharge is decreasing, which slows down the sediment transportation process. The area of the channel is affected by the changes in the river depth as the velocity of the water is decreasing.

3. RESULT

3.1 Bed Material Characteristics

The grain size distribution curve is based on the water cycle year as shown in Figure 3. The distribution curve is shown for Langat river@upstream and Langat river@downstream for both low flow and high flow season. The river flow has contributed to the settling velocity of the d_{50} particles. The bed material distribution during high-flow shows the d_{50} particle found at the downstream larger (d_{50} = 0.415 mm) than low-flow (d_{50} = 0.01mm). The particle-size distribution analysis during low-flow indicates that sand made 82% of the total river bed (coarse sand or finer) and the remaining are silt (0.01 mm – 0.06 mm). Based on the grain size analysis, an increasing trend from coarser to finer bed materials is observed based on the river flow pattern. Compared to during the high-flow season, which resulted in 80% of particle distribution, is median diameter particle. The high flow resulted in a maximum rate of particle transport. The river with sand-bed type is dominated by sand as the sediment particles are subjected to be mobilised as the water flows. The result from both measurements during low-flow and high-flow concludes that the aggradation and gradation occur at all studies reach, of which the channel replenishment rate varied between seasons.



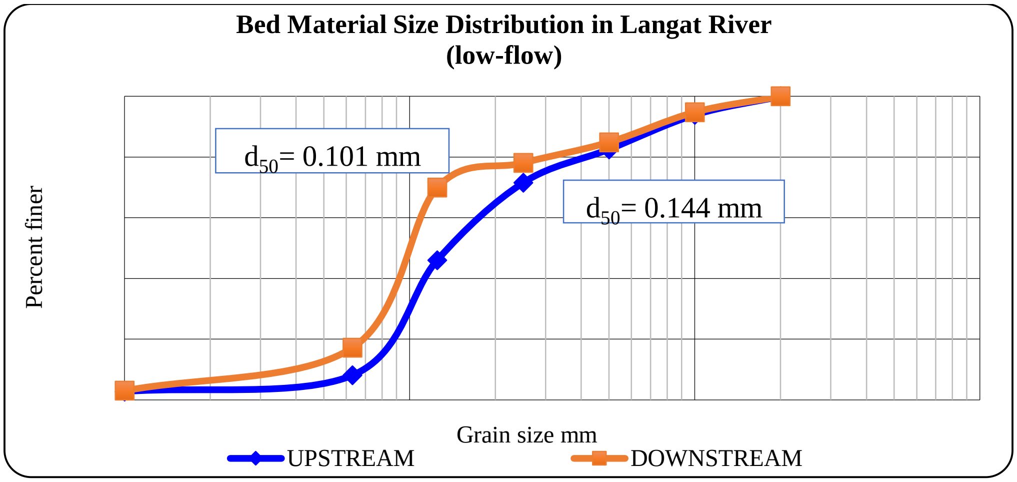


Figure 3: Division of grain size distribution from upstream to downstream in Langat River by temporal variation.

The flow pattern was observed and analysed based on the available flow gauging which has been operational for the past 35 years. Department of Irrigation and Drainage (DID) has installed flow and water level gauging both upstream and downstream of Langat river. The river flow affects the amount of sediment transported which increase downstream. The changes in depth, width and slope of the river might influence the grain size distribution from the source of production (Engelund, 1967). The extreme climate of rainfall along the year however will affect the generation of the sediment distribution in the river. The transport of sediment particle is expected to increase during the wet season due to high water discharge. From the grain size analysis of Langat River, an increasing trend from coarser to finer bed materials are observed in a downstream pattern for both seasons. This is due to the continued construction-grade sand removal from the downstream extraction station and deposition of much finer materials transported from the upstream stations could contribute to the fining of grain size population in the downstream reaches (Padmalal et al., 2013). An increase in the finer sediment at the downstream reach would cause a higher sedimentation rate, thus lowering the channel capacity of the lower reach as it is approaching the river mouth.

3.2 Sediment transport assessment

Engelund-Hansen's equation (1967), Ackers-White's equation (1973) Graf's equation (1971) and Yang's equation (1972) were selected as sediment transport equation for the analysis of 24 sets of data based on the averaged size of sediment (d_{50}). The discrepancy ratio (DR) was used to measure the performance of the equation as the ratio of the predicted load to measured load (DR=predicted/measured). The discrepancy ratio of 0.5 to 2.0 (DR = 0.5-2.0) used as standard in the evaluation of the selected equations. The assessment of these equations result is shown in Table 3. The result shows that Yang's equations produced the highest yielded percentage prediction of data sets within discrepancy ratio of 0.5 to 2.0 is 41.6%.

Table 4: Summary of sediment transport assessment.

Data no	Measured sediment load	Sediment transport equation	Total of data falls within 0.5-2.0
1	0.169	Yang's equation (1972)	Oct-24
2	0.217		
3	0.656		
4	0.191		
5	0.884		
6	0.838		
7	0.8	Engelund-hansen equation (1967)	Jan-24
8	0.564		
9	3.22		
10	4.023		
11	7.792		
12	4.25		
13	1.645	Ackers-white's equation (1973)	0/24
14	1.036		
15	4.476		
16	0.865		
17	8.252		
18	28.184		
19	2.584	Graf equation (1971)	0/24
20	18.068		
21	2.172		
22	1.277		
23	2.904		
24	1.565		

3.3 Sediment transport

Total sediment discharge is the sum of suspended-sediment discharge and bedload discharge. The total sediment discharge was used to calculate the sand replenishment volume for both low-flow (Table 5) and high-flow season (Table 6). The changes of riverbed elevation that resulted from the sand mining activity at Langat River not being under the focus of this short-duration study. Thus, the sediment transport rates are computed by using present direct hydrological data. Water discharge was measured based on 25 years ARI flood (channel-forming discharge) is 540 m^3/s. The sediment transport rate corresponds to the river flow discharge.

Replenishment volume during the low-flow season in Station 11 is the highest compared to other stations replenishment volumes. Station 11 is a control point where there is no sand mining activity happening around the area. Station 2 elevation is higher than Station 3, thus most of the fine particles that are supposed to replenish the area are washed away towards the mid and downstream areas. Besides, Station 1 and Station 2 are part of the active mining areas. The ability to keep the point in the optimum state is difficult if the amount of sand mining is higher than the river's ability to replenish. Station 3 is a control point where the sand replenishment rate will be natural compared to the others. The sand replenishment volume in Station 4 is 70% lower than in Station 3.

During the high-flow season, Station 6 showed the highest replenishment volume. The sediment discharge at Station 6 representing the downstream on Langat River shows a normal replenishment rate, with a normal range of velocity. Thus, during the high-flow season, the water discharge is two times higher than in the low-flow season. A high flow causes the riverbed sand mass to slide downward and deposited there, resulting in sediment discharge data. The river's ability to replenish depends on the activity that takes place in its system. The site-specific physical composition and changes in substrate stability are important in estimating the effect of sediment entrainment along the channel, therefore a consistent evaluation of these physical aspects are expected so that a long-term effect can be objectified. As resulted in the previous study, there is a sharp sediment-rating curve of Langat River as it is assumed to have a good rate of sand replenishment (Fang et al., 2017).

Table 5: Summary of sediment-discharge during low-flow season of Langat River, Selangor.

Sampling Station	**Water Discharge, Q (m^3/s)**	**Median Particle Diameter, d_{50} (mm)**	**Sediment Concentration, (Ct) (mg/L)**	**Sediment Discharge, Q_s (m^3/s)**	**Annual Sand Replenishment Volume (m^3)**
1	2.91	0.198	0.058	0.169	146,185
2	6.56	0.538	0.033	0.217	187,776
3	6.62	0.217	0.099	0.656	566,944
4	1.03	0.213	0.185	0.191	165,062
5	11.15	0.414	0.032	0.884	764,161
6	27.52	0.547	0.075	0.838	723,786
7	7.42	0.239	0.078	0.8	691,200
8	6.48	0.348	0.087	0.564	487,677
9	5.58	0.644	0.577	3.22	2,782,180
10	4.6	0.243	0.874	4.023	3,475,459
11	8.02	0.223	0.972	7.792	6,732,467
12	8.3	0.172	0.512	4.25	3,672,431

Table 6: Summary of sediment-discharge during high-flow season of Langat River, Selangor.

Sampling Station	Water Discharge, Q (m^3/s)	Median Particle Diameter, d_{50} (mm)	Sediment Concentration, (Ct) (mg/L)	Sediment Discharge, Q_s (m^3/s)	Annual Sand Replenishment Volume (m^3)
1	13.69	0.405	0.12	1.645	1,421,280
2	8.18	0.271	0.127	1.036	895,104
3	6.32	0.373	0.217	4.476	3,867,264
4	20.65	0.823	0.137	0.865	747,360
5	48.31	0.509	0.163	8.252	7,129,728
6	50.5	1.256	0.583	28.184	24,350,976
7	15.19	0.468	0.17	2.584	2,232,576
8	20.3	0.789	0.89	18.068	15,610,752
9	12.06	0.289	0.18	2.172	1,876,608
10	6.28	0.295	0.203	1.277	1,103,328
11	14.76	0.223	0.197	2.904	2,509,056
12	9.58	0.208	0.163	1.565	1,352,160

3.4 Optimum sand extraction volume

The sediment transport rate in m^3/s is converted into the volume of sand replenishment, m^3 in respective water discharge of the river. The estimation of the optimum extractable volume of the sand has been produced based on a 10% reduction from the annual replenishment volume of each point during the low flow period. The recommended optimum volume of sand extraction for each mining point has been tabulated in Table 6.

Table 7: Optimum sand mining in Langat River based on five critical low-flow months.

Station No.	Total optimum extractable sand (ton)* low-flow months = May to September	Monthly optimum extraction (Truck)*1 truck = 25 tons
1	10,918.42	437
2	14,024.73	561
3	42,344.33	1,694
4	12,328.27	493
5	57,074.29	2,283
6	54,058.73	2,162
7	51,624.90	2,065
8	36,423.97	1,457
9	207,797.69	8,312
10	259,577.86	10,383
11	502,839.84	20,114
12	274,289.46	10,972

As shown in the table above, Station 1 until Station 6 represent the main Langat River while the rest are from Langat River tributaries, the Beranang River and the Semenyih River. The upstream of Langat River, Station 1 and Station 2 shows that the monthly extraction during the 5 months dry period is approximately in the same range. The main river resulted in a lower optimum sand extraction volume compared to the tributaries, as the water discharge is decreasing, which slows down the sediment transportation process. The area of the channel is affected by the changes in the river depth as the velocity of the water is decreasing.

The focus of optimum sand mining extraction is during the dry period because the main factor of riverbed sand replenishment rate is the river flow rate. Water drives the particle to move from one place to another before the particle is finally deposited. The sediment loading in the channel is driven by the water flow, influenced by the rainfall pattern. As the result of this study, the rate of replenishment of Langat River is to extend the sustainability for the future practice of sand extraction and maintaining the sustainability of the hydrological system in the channel. This optimum sand extraction volume however must be revised from time to time in order to monitor the degree of bed gradation, to support the need for long-term bed incision analysis as mentioned in the earlier section.

In other words, an equilibrium state of the river cross-section is possible when the sand removal is equal to the sand inflow. When the removal is greater than the inflow, it leads to riverbed level depression and the related environmental consequences. On the other hand, if the removal is less than the inflow, it leads to sand deposition, resulting in a situation of reduction of river conveyance capacity. Reduction in conveyance capacity resulted in flood, which in turn leads to flooding, bank gullying and related economical losses. Thus an equilibrium policy is adopted here for the optimisation. The total energy that a river possesses varies from one stage to another because of the changes in the river's elevation, gradient, and speed. The sustainability of river depth in an active in-stream sand mining river is the major concern during the low-flow season to prevent future unnecessary changes in the river system.

4. DISCUSSION

There are several uncertainties in determining the actual bed load transport. Those uncertainties span from the use of measuring device, selection of sampling station and unavailable historical record from the related agency. The current usage of Halley-Smith is the best option but the duration and positioning of deploying the device may induce noise to the trapped sediment. The sampling station should represent the overall sediment load in the river system. The flow gauging should be present near the sediment sampling point as well. The limited number of flow gauging hinders the deployment of sediment measurement at various stations. The deployment of a sediment measurement device must be coupled with the flow gauging for the sediment load and sediment discharge computation. Moreover, a related agency such as DID and DOE of Malaysia are not pioneering the bed load measurement in Malaysia. The only available sediment data is suspended load at the selected river segment, making the total sediment load made of suspended load and bed load data instead.

Point 6 is the most downstream part of the study area that resulted in the highest river flow rate compared to the other points.

The river discharge and sediment discharge increased from 27.52 m^3/s to 50.5 m^3/s and 0.838 m^3/s to 28.184 m^3/s during low flow and high flow event respectively. The increase of river discharge is doubled from low flow to high flow event but the increment of sediment discharge is phenomenal (3000%), signifying the impact of a storm event on the sediment transport pattern at Langat river. The representation of bed material size increased from low flow to high flow event for most of the sampling station. The coarsening process of the river bed during storm event justified the higher sediment discharge during the high flow event as opposed to the low flow event. Box-and-Whisker plot of sand replenishment in Figure 2 showed a high discrepancy between the minimum replenishment volume ($0.14 x 10^6$ m^3) and maximum replenishment volume ($24 x 10^6$ m^3). The standard deviation of $5.57 x 10^6$ m^3 between those events (low flow and flow) indicated that the sediment transport process is not uniform at various flow events.

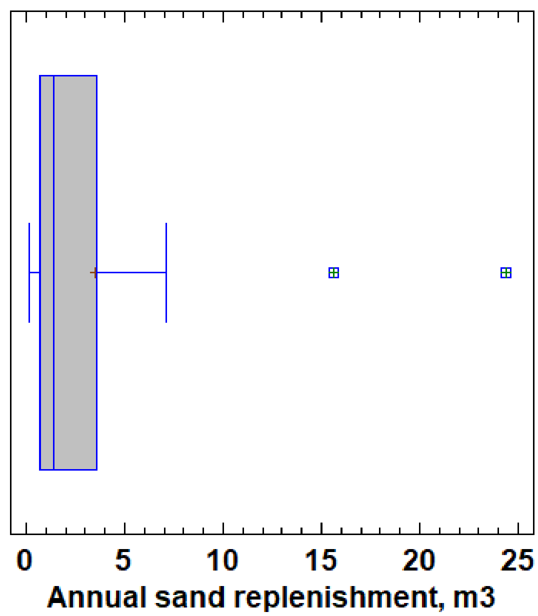


Figure 4: Box-and-Whisker plot of annual sand replenishment ($x10^6$ m^3)

The cluster analysis for each sampling station (point 1-12) revealed that the mechanics of sediment transport during low flow and high flow event acted differently. Each station formed a different hierarchy of clusters as depicted in Figure 3. As such, sampling point no. 6 formed the same hierarchy with sampling point 1, 4, 2, 3, 8, 5 and 7 during low flow event but acted independently during high flow event. Thus, the sediment discharge at the sampling point varies and is unique to each station and the measurement must be conducted independently for each station to obtain sediment discharge.

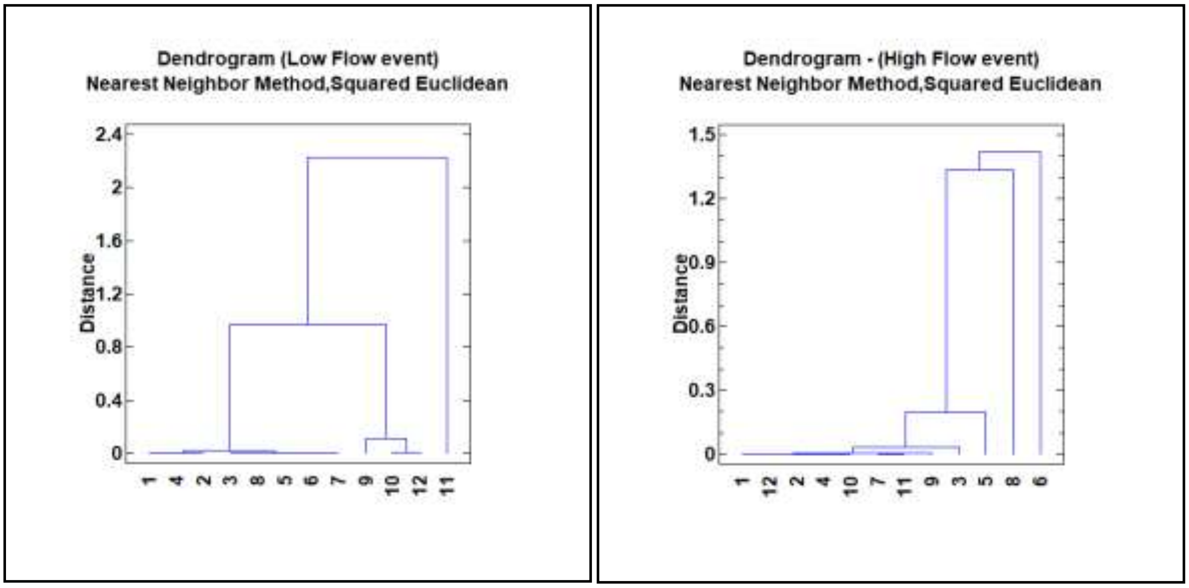


Figure 5: Dendrogram plot of sand replenishment volume

The sand replenishment rate at each extraction points in the study area was successfully estimated as well as the computation of the estimated sediment discharge using the Yang equation. The sediment discharge downstream is higher as the water discharge increases. The downstream sand replenishment rate is increasing as the water flow flushes the sediment from upstream and transported to the downstream part of the river before the deposition occurs. During this high-flow period, a scouring process takes place as a result of the turbulence. Hence, the deposition is comparatively low, thus an assumption was made such that 70% of the sand transported is deposited during the high-flow period. The deposition is assumed to be of about 90% as a result of the low velocity recorded in river systems.

5. CONCLUSION

The average sediment discharge from low-flow to high-flow event increased from 1.43 m3/s to 6.50 m3/s signifying the impact of a storm event on the sediment transport process. The increment of 354% for the average sediment discharge is a manifestation of the flushing rate that Langat River can produce during the storm event. The optimal sand extraction in the main Langat River (based on the number of 25 tons truck) during the critical period is 437 trucks to 2,144 trucks. With the recommendation on a calculated optimum volume of extraction, an early warning and prevention of over-extraction can be provided and the river system can remain unharmed and sustainable. . The approval of extraction rates must be less than the estimated amount that is transported to the mining point from upstream on an annual average basis. Recognising the large variability in annual sediment transport and the actual sediment transport in any given year is typically much less than or much more than the annual average rate and site-specific considerations. Analysis of sequential aerial photographs to measure channel change induced by past extraction and intervening floods and gravel extraction should be conducted as a considerable fraction of the bedload arriving at a site is allowed to pass on to downstream bars.

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