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Variation of Suspended Sediment Concentration during Storm Events in Upstream Bernam Rivers, Selangor Malaysia

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Abstract

Recently, the water quality in Bernam River has deteriorated due to sedimentation processes and unbalanced development around the river basin. This study was conducted to measure and compare the suspended sediment concentration between the low flow and high flow. In this study, sampling was conducted on 9 October 2019 until 26 February 2020 in three sampling stations during the normal season and rainy season. The results of the study demonstrated high suspended sediment concentration on 29 January 2020 in the three stations with values of 972.6 mg/L, 2152.4 mg/L and 1408.2 mg/L. However, the change in the suspended sediment concentration during the rainy season at station 1 is the highest, which was 2114.2 mg/L. The results of regression analysis in this study shows that the relationship between discharge and suspended sediment concentration is significant, with R^2=0.5. The relationship between the discharge and water depth (stage) at the selected research sites shows a very significant relationship, with R^2=0.9, R^2=0.8 and R^2=0.8. This proves a strong relationship between suspended sediment production and changes in land use that occur around this basin. The results of the study found that the high suspended sediment concentration is due to the changes in land use and weather factors such as rain and groundwater runoff which eventually gets into the river thus further increase the suspended sediment.

Keywords: Bernam River, low flow, high flow and suspended sediment concentration

INTRODUCTION

Land use development is an ongoing activity and is required by every country to generate a better economy and social aspect. This has led to various issues related to land use such as forest areas replaced by the opening of new land and agricultural areas, in line with the rapid increase in population, this also puts huge pressure on the natural resources (Nur Syabeera Begum & Firuza Begham, 2019). Green trees that serve as the soil cover can indeed reduce the occurrences of erosion. However, if there are changes in land use due to development, this does contribute to rapid increase in the erosion rate. Soil degradation is one of the major environmental issues worldwide and the impact also increases in the North American Region, Australia and Southern Europe (Bajocco et al., 2012). Soil resulting from degradation and erosion is no beneficial to flora and fauna, in fact, it also damages the environment and causes great losses to the country.

The situation is deemed to take place due to a housing project in Taman Bernam, Tanjong Malim as a result of land clearance and land excavation to construct drainage so that water flows to Bernam River (Berita Harian Online, 2020). Along with the rapid development of land use, this contributes to many issues, especially those related to environmental pollution, land conflicts and the reduction of open/vacant land for future use (Zurinah & Jalaluddin, 2017). However, there is another issue, where the houses that should have been there are yet to be constructed, yet the septic tank is built earlier (Astro Awani, 2020). This raises concerns among the locals, especially the residents of Kampung Simpang Empat, Tanjong Malim, when they had witnessed the river conditions during the rainfall caused by mud residue going down from the housing area into the drainage and flows into the river area. As a result, this causes the colour of the river to turn brown and becomes turbid due to the soil and mud residues from the residential areas. Based on observations that have been carried out, the quality of Bernam River is affected because it is now physically polluted and the resulting sediment will causes the water to be cloudy, dirty and eventually the river becomes shallow (Aduan Rakyat Online, 2020).

Today, soil erosion contribute to the water pollution issues in ponds, lakes, rivers and oceans. Serious water pollution does no longer benefits life, but also causes huge losses to a country. As proven in the Department of Irrigation and Drainage Annual Report 2017, the cost of excavating river estuaries to deepen and remove sediment deposit in 2017 is RM 346,564,216.73 (Jabatan Pengairan & Saliran, 2017). Therefore, sedimentation problem in drainage requires high cost to be fixed and it is time consuming, so there is a need for a faster method to measure the suspended sediment concentration to get to know the relationship between rainfall and the amount of suspended sediment.

Suspended Sediment Concentration

In general, sediments consist of various shapes and sizes, they can be small such as sand, small pebbles and silt or the even larger ones such as bedrock that is usually be found in the river upstream. Sediment deposition in river estuaries usually involves finer sediments such as sand and silt (Mohd Khairul Amri et al., 2014). All of this material becomes a major sediment transport in streams from the river basin to the sea. Therefore, the determining factors to the source of sediment production consist of natural aspects such as rainfall as well as anthropogenic aspects such as the effects of land use, which include agricultural, construction and mining activities. The process of sediment transport involves the process of removal of surface materials due to erosion in the surrounding and then the suspended sediment will flow from the original location to the new location before settling in the riverbed (Sumayyah Aimi, 2016).

River sedimentation has been a crucial issue in the field of earth and environmental sciences. So far, river sedimentation is studied worldwide, for example, to see how sedimentation is influenced by climate change and human impacts. Menurut Ouellet-Proulx et al., (2016), there are three factors that influence the amount of suspended sediment in a system, namely hydrology, meteorology and physiography. Hydrological variables such as rain, snow and wind are widely available and easy to analyse. According to Civeira et al., (2016), river transport and sedimentation refers to the factors of amount of water, discharge, sedimentation, topographic and environmental features, human impacts as well as the amount of sediment transported by the river stream. The Integrated River Basin Management (IRBM) is a water resources management approach associated with resources including social and economic activities that covering environmental management aspects such as issues in land use, pollution control, development pressures and biodiversity conservation in river basins such as water flow for hydroelectric power and irrigation , soil erosion control and ecological restoration (Chuan et al., 2013). Therefore, changes in the soil use patterns are significant in influencing water quality, for instance, rapid development activities carried out in river basins have resulted in different effects on river basins than before (Song et al., 2020).

According to Dai et al. (2016), suspended sediment concentration is a major variable in rivers, in relation to the transport of contaminants, water quality, suspended sediment reservoir, soil erosion and its effect on ecology and recreation. An influx of sediments will cause damage and disrupt the river system as well as bring many problems in the river ecosystem and human life. This affects water quality, the oxygen concentration level in the water, water level and the ability of the river to house aquatic life and its surroundings as a habitat. In addition, the function of river becomes more passive for human use in many economic sectors of land use such as urbanisation, tourism and recreation, public facilities, residential area and so on (Tuan Pah Rokiah & Hamidi, 2016). Erosion affects soil stability as well as increases sedimentation in natural streams, rivers and lakes, especially nearby development sites. Hill cutting is carried out to cover the gully erosions that are formed in the developed hill areas. Implicitly, this contributes to the occurrence of surface erosion, causing all sedimentary materials to be transported into rivers and lakes. This also occurred at Universiti Kebangsaan Malaysia (UKM) when the secondary forest was explored to develop the new Faculty of Science and Technology (FST) building, this area experienced erosion, thus contributing to sedimentation in the stream of Alur Ilmu (Mokhtar & Hafizi, 2016).

Research Sites

Bernam River river basin encompasses certain sub-basins based on its tributaries, namely Trolak River, Erong River, Bernam River, Inki River and Slim River. The first sub-area that is selected in this study is Bernam River, it is located in the southern part of Perak and northeast of Selangor while the second sub-are is Inki River in Hulu Selangor. Bernam River flows from Mount Liang Timur located in the east of Titiwangsa Mountain with an altitude of 1933 meters. The terrain of Tanjong Malim is irrigated by Bernam River and flows directly to Kuala Sungai Bernam in Sabak Bernam while the western part of Tanjong Malim in the state of Selangor is filled with swamp forest, which is at Tengi River. The area has been reclaimed and dried up by a drainage and converted for oil palm plantation. According to Adiyiah et al., (2013), the downstream and upstream rivers have different qualities because most of land uses take place in the downstream areas while there is no land use in the upstream areas.

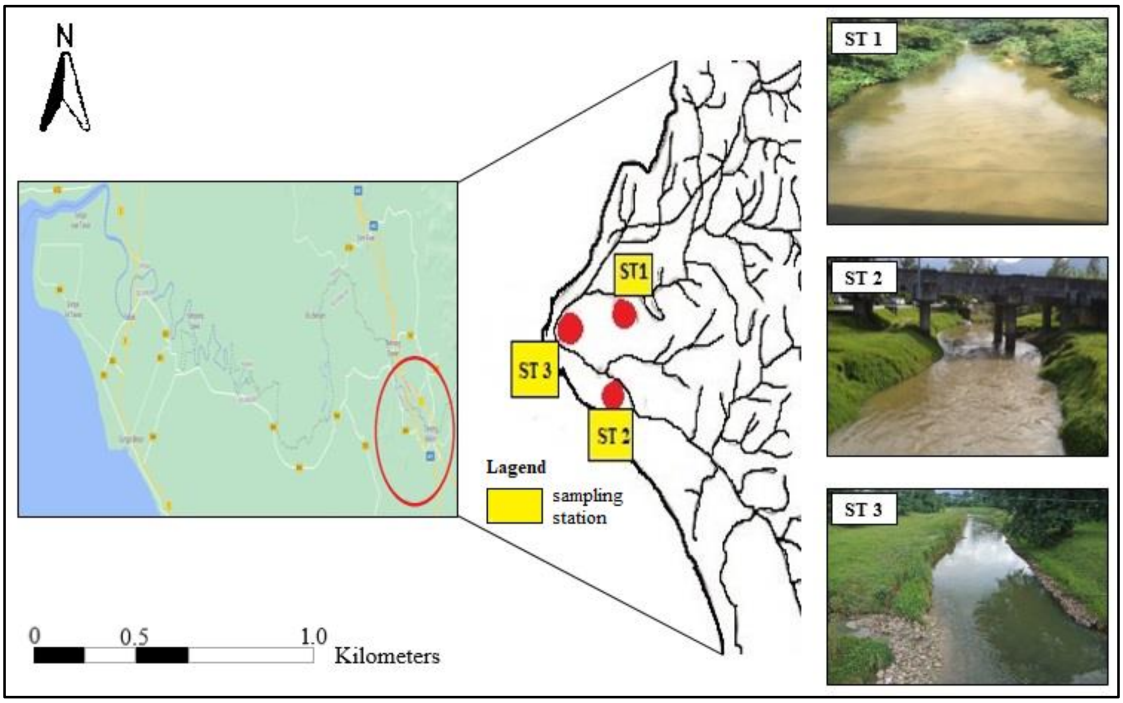

Figure 1. Sampling location by station in the Bernam River sub-basins (Bernam River and Inki River)

Table 1. Location of sampling stations at the research sites

Station	Latitude	Longitude	River	Research location
1	3°40'51.9"N	101°31'49.3"E	Bernam River	Hulu Bernam Bridge
2	3°40'25.3"N	101°31'41.8"E	Inki River	Bridge (Residential Area)
3	3°40'40.2"N	101°31'15.2"E	Bernam River	Tanjong Malim Bridge

Land use development in the research sites were developed with many projects that include residential area, factories, agriculture, infrastructure and utilities, community institutions and facilities, commercial and transportation areas. The remaining areas are occupied by rivers, forest, vacant land, open land and recreation site, as well as mixed development site (refer to Figure 2). The area of land use development in the research sites in 2019 is 452.03 hectares. This study covers two rivers, in the state of Perak is Bernam River while the river in the state of Selangor is Inki River. The land use of the research sites consist of water bodies or rivers (41.67 hectares), forest (15.13 hectares), infrastructure and utilities (2.10 hectares), community institutions and facilities (48.37 hectares), commercial (22.32 hectares), transportation (117.47 hectares), agriculture (131. 21 hectares), residential area (53.38 hectares), open land and recreation site (4.66 hectares) and others (15.72 hectares).

Figure 2. Map of land use of the research sites in 2019.
***Source*:** Adapted from (Jabatan Perancangan Bandar dan Desa, 2020)

METHODOLOGY

To fulfil the research framework, sample selection and statistical methods are the most important aspects. Three sub-basins in Bernam River Basin was selected as the area for sample collection, in which many observations were conducted. The collection of all samples in the research site is small and the natural characteristics of the areas are standardised. These three sub-basins were characterised and data from these areas were analysed in stages for the purpose of easier identification and explanation of the study criteria as well as the stages of implementation in this study.

Sampling Method

Water sampling is the primary data, where the data was obtained via filed observation at several sampling locations in the sub-basins of Bernam River and Inki River. The sampling was conducted in five months, starting from October 2019 to February 2020. Three river stations in the Bernam River Basin were selected and observation was conducted once a week. The sediment parameters that are determined in situ are water velocity (v), river width (d) and river depth (w) to focus on the concentration and amount of suspended sediment. This method involves sampling at these three sampling stations using the grab sampling method. Grab sampling is based on the method proposed by the United Nations Environment Program and the World Health Organization (Bartram et al., 1996). Therefore, the field method focuses on the evaluation of suspended solid concentration in two Bernam sub-basins and one Inki sub-basin. Data were obtained through field method. Observation conducted in the research sites is a must to provide the initial picture of the river conditions. This is because the rivers will change their colour in the event of rainfall. This is the beginning to obtain materials and information for data collection in the study area. It is important to measure the cross-sectional area of the sampling sites to provide an overview of the cross-sectional shape of the selected rivers and to take into account the discharge for each river (Figure 3).

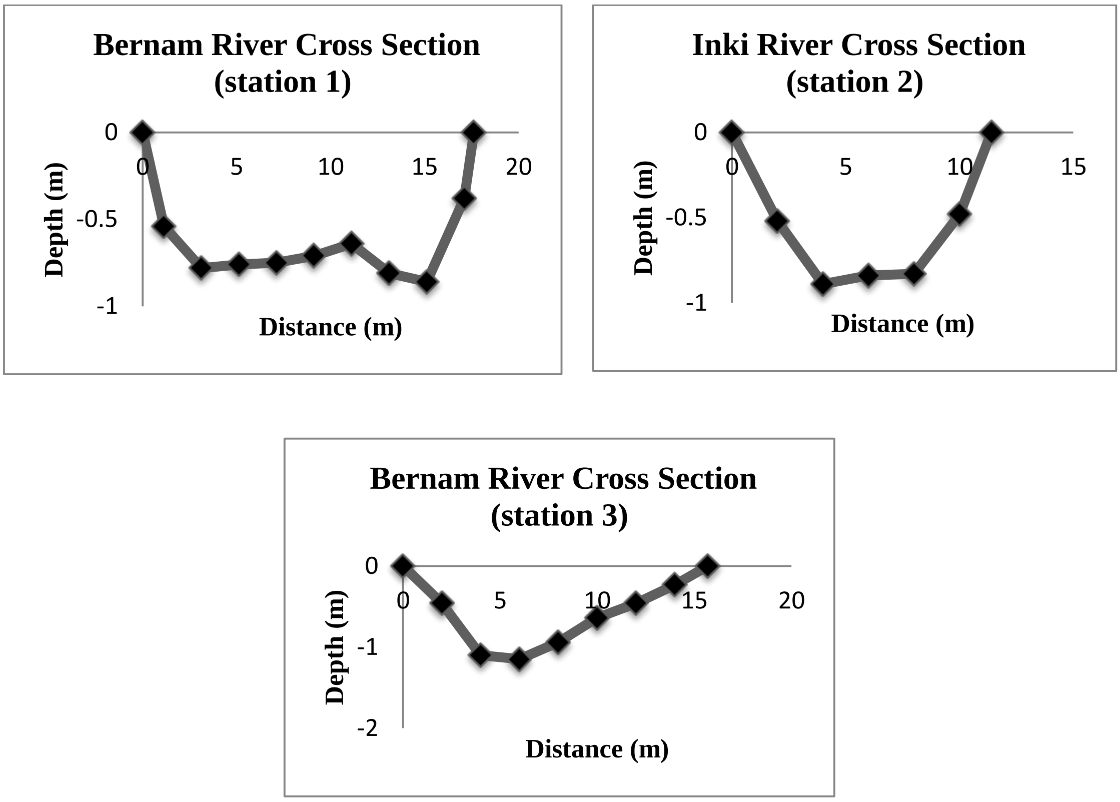

Figure 3. Cross section of the three stations in Bernam River and Inki River

According to Sumayyah Aimi (2016), the average vertical velocity and depth of each sub-section boundary will be used and multiplied by the width of that sub-section or segment. The following is the formula to measure the area of a triangular segment:

Area = ½ x depth x width of the segment
= ½ x a x b

If the area of the segment is trapezoid, then the formula to be used is as follows:

Area = ½ x c (b + d)
Where b = Depth in the first section
d = Depth in the second section
c = Width

According Gordon et al., (1922), water samples obtained from the field area represents three segments namely 1, 2 and 3. Each segment will be represented based on the method when an individual faces the river current, the right side represents A, the middle side represents B while the left side represents C. Water samples of 500 mL were collected from each part of the river in replicate. Next, the depth of the river was measured manually using a plumb. River depth was measured to determine the pattern of change in depth of the river associated with sediment transport. According to Wan Ruslan, Narimah, & Nooriah (2014), river discharge is the volume of water that flows through a point of the river flow at a given time. Normally, the river discharge is measured using a current meter in cubic meter per second. The discharge also depends on the volume of water and the velocity of the river current. In addition, the buoyancy method is used to measure the current speed. According to Gordon, Mcmohan, & Finlayson (1922), the net weight obtained represents the amount of suspended sediment in the unit of gram per litre. The velocity formula is as follows:

V = Distance/Time
= d/t

Water level is measured manually using a measuring stick. Water depth can also be measured using various methods using the environment and physical characteristics of a river, that is, using plumb and graduated measuring stick in the unit of cm. This method uses a flow meter to measure the velocity of current (V) and discharge (Q), which is obtained by multiplying the cross-sectional area (A) by velocity (V). Next, the calculation of river discharge is simplified using the following equation (Shaw, 1988);

$Q = V$ (m/s) x A (m^2)
= $m^3\ s^{-1}$

Where;
Q is the river discharge in the unit of m^3 per second (m^3/s)
V is the velocity of the river current in the unit of meter per second (m/s)
A is the cross-sectional area in the unit of m^2

Due to the non-uniform water depth and flow velocity for the entire cross section, the water discharge can only be measured accurately by dividing the cross section into a series of sub-areas known as sections. Each section is bounded by surface water, the riverbed and two imaginary vertical lines known as verticals (Figure 4). Each vertical is a common dimension of two contiguous sections and the water depth and current velocity are set when the observations are carried out. Sufficient velocities were observed out to obtain the average velocity at each vertical boundary of a section and the average velocity (e.g., V1, V2). So, the average velocity of a section is:

e.g. $$V1,2 = \frac{V1 + V2}{2}$$

Each section is calculated by averaging the depths of d1 and d2 at the vertical boundaries and multiplied by the distance between the vertical boundaries as follows:

e.g. $$a1,2 = \frac{(d1 + d2)\ w1,2}{2}$$

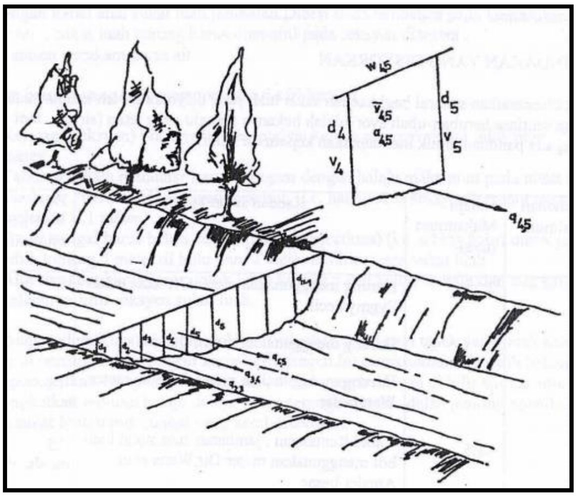

Figure 4. Discharge measurement theory

Furthermore, the laboratory sampling method to analyse the parameters could not be carried out at the research sites directly. Water samples collected from each station were analysed at the laboratory of Faculty of Geography in Universiti Pendidikan Sultan Idris (UPSI) to obtain the suspended sediment concentration readings via filtration using the Whatman GFC filter paper. The parameter that was tested in the laboratory is the suspended solid sediments (SS). The total suspended sediment (TSS) analysis as in Figure 5 was carried out to determine the concentration and load of the suspended sediment in the water samples to represent the river at each station. According to Brebbia et al., (2015), sediments in this context refer to insoluble substances found in river, causing the water to look turbid. The amount of suspended sediments does include all suspended particles and insoluble material, in which the sediments will be filtered using the filter paper.

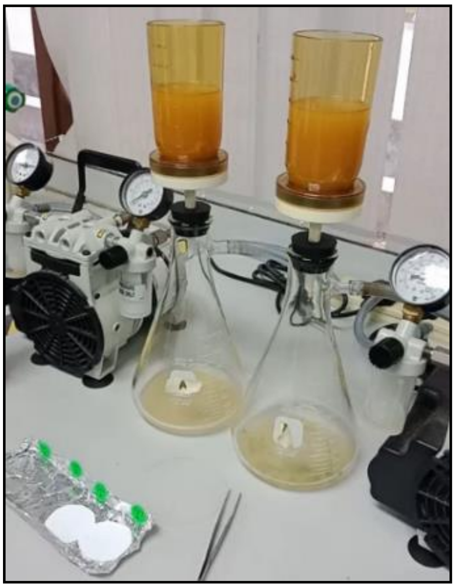

Figure 5. Analysis using vacuum pump filtration and filter paper (Glass Fiber Filter) Suspended sediments that are classified as non-point pollutant are the soil particles formed from the erosion of hills or construction areas that get transported into the river through the surface runoff. According to Gordon et al. (1922), the net weight obtained represents the amount of suspended sediments in the unit of gram per litre.

Suspended sediment concentration (mg/L) = [(Wb – Wa) / V] x 1000 x 1000

Where;
Wa = weight of paper before filtration (g)
Wb = weight of paper after filtration (g)
V = volume of water sample (millilitres)

Data Analysis Methods

Data and information obtained via field observations were analysed using Microsoft Excel software (EXCEL 2016). Descriptive analyses such as range, minimum, maximum, mean and standard deviation of the suspended sediment concentration were obtained from the data observed from October 2019 to February 2020. Linear regression analysis was used to identify the relationship between discharge and suspended sediment concentration in the normal season and rainy season. This analysis was also used to look at the relationship between river discharge and depth for each station.

RESULTS AND DISCUSSION

Suspended Sediment Concentration

Overall, the suspended sediment concentrations at each station are different throughout the observation period. The total suspended sediment concentration at Station 1 over 21 weeks was 972.6 mg/L. During the observation period, the maximum suspended sediment concentration at Station 1 was recorded on 1 November 2019, with total concentrations of 369.8 mg/L and 470.8 mg/L on 29 January 2020. This is due to the more aggressive sedimentation, resulting from the exploration of hill forest for residential purpose. Figure 6 shows the observations in Bernam River during the normal season and rainy season in detail. Soil erosion in the construction area is more rapid due to high rainfall, where the suspended sediment concentration of 972.6 mg/L is categorised in class V (> 301), this condition is not feasible to conduct economic activities for humans or livestock.

Figure 6. Bernam River conditions during the normal season and rainy season

Station 2 in Inki River received a total suspended sediment concentration of 2152.4 mg/L, indicating this station has the highest suspended sediment concentration in comparison to the other two. During the observation period, the maximum suspended sediment concentrations at Station 2 were 297.2 mg/L on 1 November 2019 and 1229 mg/L on 29 January 2020. Station 2 with the highest suspended sediment throughout the observation was categorised in class V (> 301), for the amount that is more than 301 mg/L (Figure 7). Based on the observations, the suspended sediment concentration in this river is likely due to human factors and economic activities such as agriculture, livestock and solid waste produced from residential areas, as well as assisted by the physical factors.

Figure 7. Inki River conditions during the normal season and rainy season

Meanwhile, Station 3 is the downstream area of Bernam River that separate the two states (Selangor and Perak) is the river outlet of Station 1 and Station 2. The maximum suspended sediment concentrations throughout the observation period was 340.4 mg/L on 1 November 2019 and 645.2 mg/L on 29 January 2020. However, the total suspended sediment concentration at this station is 1 408.2 mg/L, which is categorised in class V for the concentration of more than 301 mg/L. This indicates the high suspended sediment concentrations in the river occur due to both physical and natural factors (Figure 8).

The overall rate of change in the suspended sediment concentration

In this study, the changes in the rate of suspended sediment concentration for each station were recorded over a period of 21 weeks i.e., five months (October 2019 to February 2020), as illustrated in Figure 9. The suspended sediment concentration for the three stations in River Bernam and Inki River demonstrated the extreme rate of change from 9 October 2019 to 26 February 2020.

During the sampling period, the highest suspended sediment concentration was recorded on 29 February 2020 at three temporary stations of Station 3 in Bernam River, which is the river outlet for Station 1 and Station 2 at a moderate rate. It was observed these three stations have high sediment concentrations on January 29, 2020, where the values were 972.6 mg/L for Station 1, 2 152.4 mg/L for Station 2 and 1 408.2 mg/L for Station 3. However, each station has its own concentration, which is attributed to natural factors and human land use activities.

***Figure 8*.** The conditions of Bernam River at Tanjong Malim Station (ST 3) during the normal season and rainy season

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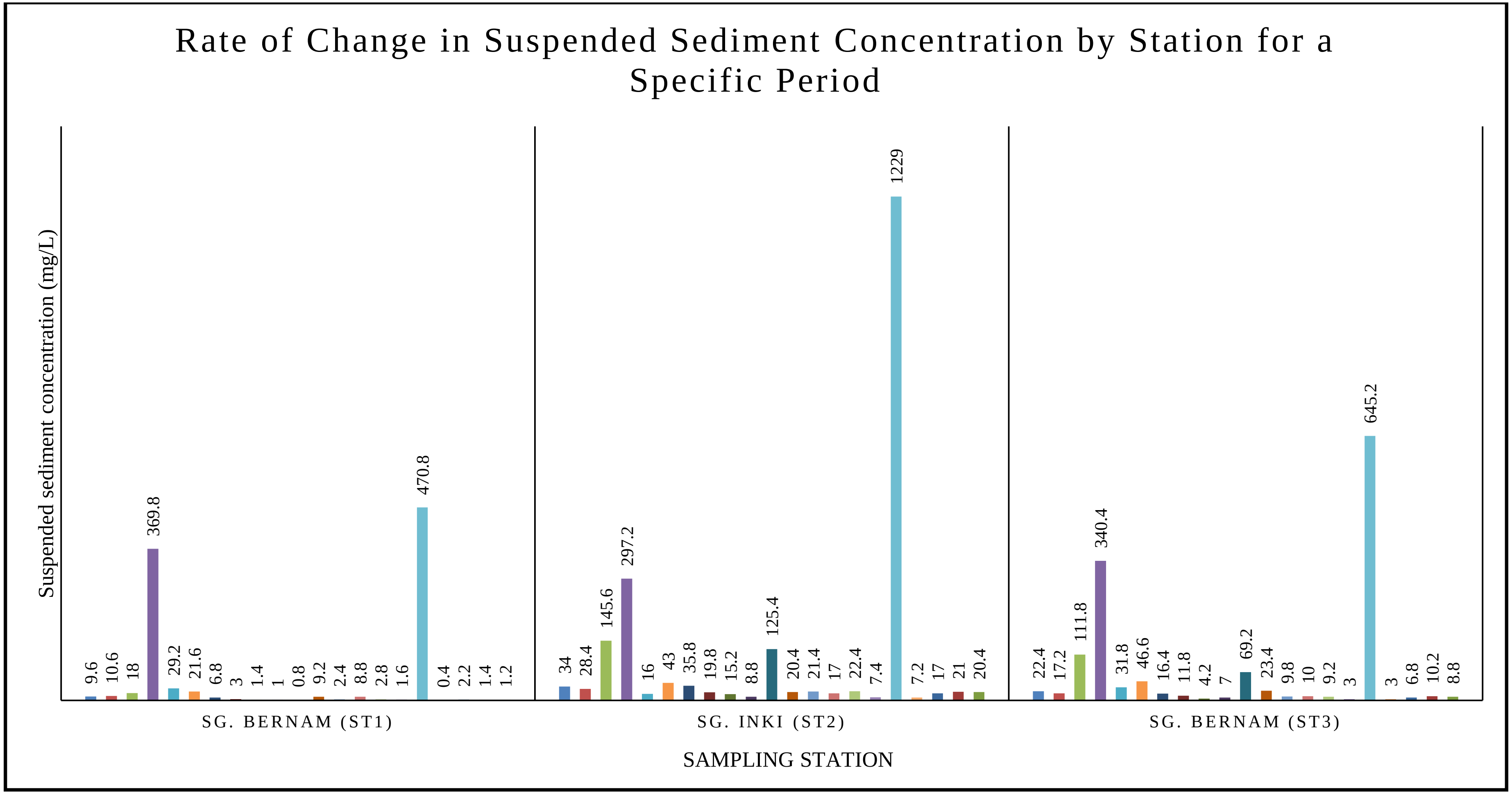

Figure 9. Changes in the suspended sediment concentration according to station over 21 weeks in Bernam River and Inki River in October 2019 to February 2020

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Rate of change of suspended sediment concentration during rainfall

Based on this study, the change in the rate of suspended sediment concentration during rainfall during the sampling period only for each station was recorded from October 2019 to February 2020. The rate of change in suspended sediment concentration for the three stations, namely Bernam River and Inki River, respectively, reflects the extreme rate of change from 9 October 2019 to 29 January 2020. Figure 10 clearly shows that these three stations have high and significant suspended sediment concentration values. However, seen between these three stations shows that on the four days from October 9, 2019 to October 23, 2019 is very high value of suspended sediment concentration for each station. This is due to active land use for the purpose of construction of residential areas, the sedimentation is facilitated by hydrological such as heavy rainfall. Thus, the eroded construction sites and surface runoff carry soils into the river, contributing to the suspended sediment concentration, as illustrated in Figure 11.

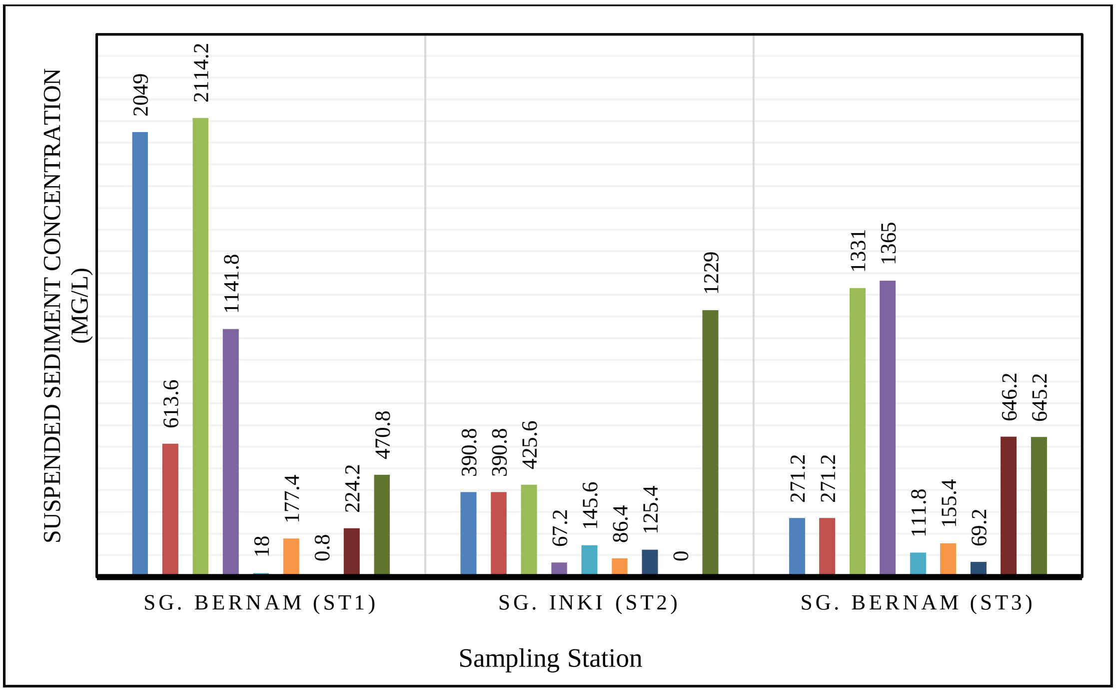

Figure 10. Total suspended sediment concentration during rainfall according to station in Bernam River and Inki River from October 2019 to February 2020

Figure 11. Bernam River at Tanjung Malim is turbid station during rainfall

Analysis of the relationship between river depth and discharge

The results of the cross-sectional area and suspended sediment concentration of each station were obtained and analysed. The discharge and suspended sediment concentration of each station were determined and analysed, including those in the normal season as well as the rainy season. The regression analyses of the relationship between discharge and river depth (water level) of each station in Bernam River and Inki River are illustrated in Figure 12, Figure 13 and Figure 14. Figure 12 shows that the regression level of Station 1 is strong with R^2=0.9. The regression value is determined from the river environment that contributes to the high flow regime or sedimentation. In addition, the regression value illustrates the positive and strong relationship between discharge and river depth, which may be influenced by physical factors such as rainfall, seasonality and land use activities. Therefore, this situation causes an increase in the suspended sediment concentration in Bernam River.

Station 2 which is in Inki River also shows a high and strong relationship of R^2=0.8. Figure 13 illustrates a positive relationship, where the increase in river discharge and water depth results in high suspended sediment concentration in Inki River. This is because the location in this study experienced disruption where the water flow had caused the collapse of the upper area of the riverbank, besides the influx of contaminants from the smaller rivers further increase the river discharge. Therefore, this contributes to an increase in the suspended sediment concentration and further reduces the depth of the river.

For Station 3, the regression analysis shows that a strong relationship with R^2 = 0.8, this is explained by the variation in the discharge at Tanjong Malim station of Bernam River (Figure 14). The positive relationship indicates the high river discharge at Station 3 was due to the amount of discharge received from Station 1 and Station 2. This is because Station 3 is located in the downstream area and is the river outlet from the rivers in the upper area. Therefore, it was observed Station 3 had high suspended sediment concentration due to human activities such as land use, agriculture, business, inland fisheries and so on.

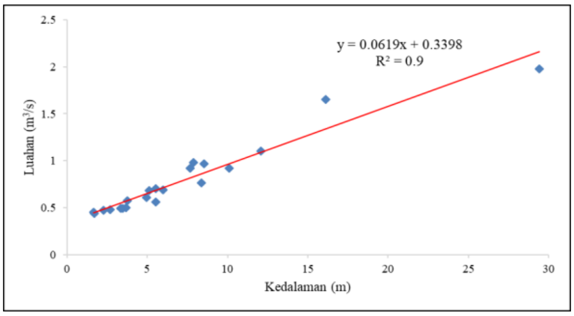

Figure 12. The discharge rate curve at Station 1, Bernam River

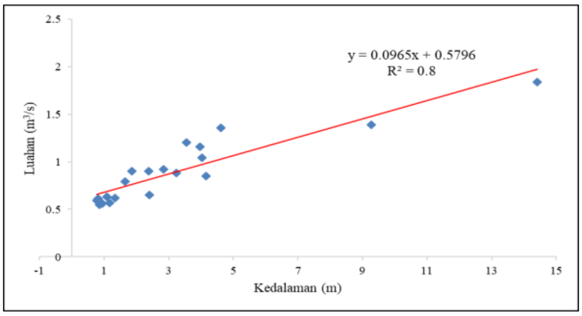

Figure 13. The discharge rate curve at Station 2, Inki River

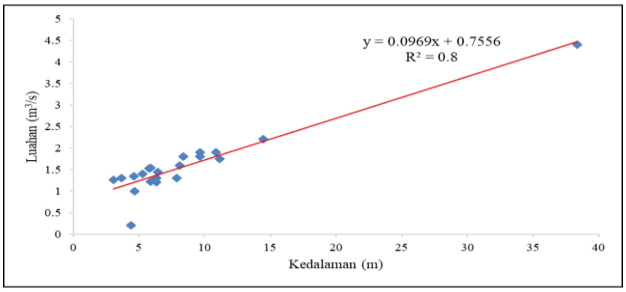

Figure 14. The discharge rate curve at Station 3, Bernam River

CONCLUSION

Overall, it was found that there is a huge difference of suspended sediment concentration between the normal season and the rainy season. Based on the findings in this study, it was found that the observed suspended sediment concentrations vary from week to week, this depends on weather factors such as rainfall in the sampling stations and because of land use activities. The weekly suspended sediment concentration during the normal season is lower because the influence of weather factors i.e. rainfall is minimal. Rainfall triggers surface runoff, thus causing soil erosion and the eroded particles are then transported into the river. In addition, the environment of the research sites can still be controlled by the inclusion of small suspended sediments such as dried leaves and twigs, this is known as the gravity and dissolving processes in the river.

Meanwhile during the rainy season, there is a huge difference in terms of the amount of suspended sediments in comparison to the normal season. The average suspended sediment concentration in the research site, especially Station 1 in Bernam River was found to be high, driven by human activities such as land use in the upstream area. Changes in land use have occurred in Taman Bernam, Tanjong Malim for residential purposes. Taman Bernam was originally hill forest, but since the area was converted for residential purpose, this contributed to water pollution in Bernam River. Observations made also found that the weather factor such as rainfall increases the suspended sediment concentration in the research sites. The suspended sediment concentration was found to increase upon rainfall due to soil erosion, because not all raindrops that falls on the soil get infiltrated into the soil. In fact, the mechanical force of the surface runoff leads to erosion on the soil surface, that eventually get transported into the river.

Overall, this study found that the total suspended solid concentrations of Bernam River and Inki River are at level V according to the water quality index, especially during rainfall. This water quality indexes in Bernam River and Inki River are at level V, with 972.6 mg/L in Station 1, 152.4 mg/L in Station 2 and 1408.2 mg/L in Station 3. Therefore, Bernam River is still suitable to house aquatic life and economically viable. However, Inki River is unsuitable for all activities, especially during the low flow in the normal season. In fact, Station 3 is the area of economic activities for the population, sometimes, there is inland fishing activity, this happens because Station 3 is the river outlet that receives and combines the water flowing from Station 1 and Station 2.

However, if no action taken to preserve the river conditions in the best way, over time Bernam River and Inki River will get more contaminated, thus affecting the life surrounding them. This is because the land use activities carried out along Bernam River for residential purpose and agriculture as well as sand mining, plantation and residential area along Inki River may get worse from day to day. If the activities are left uncontrolled, one day Bernam River and Inki River will be severely contaminated and unable to house any aquatic organisms in the future. Therefore, there are some recommendations and measures to preserve the rivers, such as stricter law enforcement, to control erosion on the soil surface and riverbanks, to control development activities as well as educational programmes and awareness campaigns.

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