A Study on Tuaran River Channel Planform and the Effect of Sand Extraction on River Bed Sediments

Jayawati Montoi[1#], Siti Rahayu Mohd. Hashim[2], Sanudin Tahir[1]

1 Geology Programme, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA.
2 Mathematic With Economic Programme, Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA.
Corresponding author. E-Mail: jfshakim@gmail.com; Tel: +6088-260311; Fax: +6088-240150.

ABSTRACT River sand extraction is known as one of the main factors that induces the significant changes on river planform. This paper main objective is to study on the significance of planform changes on Tuaran River from 2003 to 2016 and sediment composition changes due to this activity. The study on channel planform focuses on four single wavelength channel bends which are located at the downstream of Tuaran River. Two meander features which are the channel width (w) and radius of curvature (Rc) were measured from digitized Google Earth satellite image year 2003, 2013, 2014 and 2016 and overlay with the Department of Survey and Mapping Malaysia (JUPEM) topographic map using Geographic Information System (GIS) software and georeferenced to World Geodetic System (WGS) 1984. Four sites which are located at the downstream of Tuaran River were selected to determine the river bed sediments composition. Three of the four sites are located at the sand extraction area whilst one site is a controlled area with no sand extraction activity. River bed sediments were collected and the sediments composition was analyzed using Mann Whitney and Kruskal-Wallis tests to determine the composition difference between the areas and the inner parts of the river. The analyses result showed that the pattern of channel planform changed throughout the years except between 2013 and 2014. Sand extraction activity altered river planform at a faster rate than normal river process where the reduction width of the river in this extraction area is significantly larger. Mann Whitney test on the river bed sediment shows that sediment composition is significantly differed with respect to the areas. Meanwhile, the Kruskal Wallis test showed that the area with no sand extraction has a significant difference in particles mean size between the outer bank, inner bank and middle part of the river unlike the area with active sand extraction. These findings proved that sand extraction activity has changed the river bed sediments distribution in extent changing the channel planform of the Tuaran River.

KEYWORDS: River planform, Sand extraction, Bed sediment, River bank, Kruskall-Wallis test.

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INTRODUCTION

River sand extraction is a removal process of sediment from river bed either using heavy machineries or suction dredges. Extraction activities in obtaining river sediment such as sand and gravel are very common nowadays due to rapid urban development and lacking alternative sediment sources (Kondolf, 1994; Rinaldi *et al*., 2005). Furthermore, river sediment has several advantages such as (a) the material is durable, rounded and well-sorted; (b) located near the markets or transportation routes, minimize the transportation costs; (c) channel sediment can be easily quarried so the extraction and processing of the material is relatively low cost and (d) it is a renewable resource through sediment transport processes (Kondolf, 1994).

Sediment removal directly alters the channel geometry and bed elevation (Kondolf, 1997). Although it has a positive economic impact, this activity may also contribute to the negative changes in the river environment for either short or long periods. When the rate of sediment extraction exceeds the replenishment rate of these materials, it will eventually leads to many environmental issues (Kondolf, 1994; Padmalal *et al*., 2008; Ashraf *et al*., 2011). Excessive river sand extraction activities produces many kinds of physical effects such as impacts to infrastructures (Kondolf, 1997), channel instability eg. lateral changes, changes in channel width and morphology (Surian & Rinaldi,

2003) and downstream and upstream incision (Kondolf, 1994; Surian & Rinaldi, 2003; Marston *et al*., 2003). And according to Hickin and Nanson (1984) local channel migration determined the sediment loads in the meandering alluvial channel.

Sand extraction is of great importance not only to the Sabah economy but also to Tuaran District. According to EPD (2013) sand extraction at Sungai Tuaran averaging 115,000 m^3/year for construction purposes alone. This contrasts with an estimated annual sediment supply of 95,000 m^3/year resulting in a sediment deficit 1.2 times than sediment yield. It is clearly implying that the sand extraction in Tuaran River is not sustainable and has led to river bank and coastline erosion. River sand extraction at Tuaran River not only involves physical removal of sediment from river bed using suction dredges but includes washing and screening the sediment at the riparian reserves and stockpiling of sediment. This activity basically contributes to sedimentation of fine particles (Frings, 2008; Ashraf *et al*., 2011), altering flood magnitude and frequency (Rinaldi *et al*., 2005), reducing sediment availability, changing sediment dynamics and inducing bed incision (Kondolf, 1997). Therefore the aim of this paper is to identify and to evaluate the planform channel and the sediment composition change due to this excessive river sand extraction activity at Tuaran River.

STUDY BACKGROUND

Tuaran River is located within Tuaran River Basin in Tuaran District, Sabah. The whole catchment covers an area of 988 km^2 with eight major channel tributaries that originate from the Crocker Range and flow generally westwards to the South China Sea. Tuaran River is the main water supply for industrial, domestic and agricultural uses around Tuaran and Kota Kinabalu districts. Tuaran Catchment can be divided into three physiographical distinct zones—the highlands >200 m above mean sea level (m.s.l), hilly and undulating (20 – 200 m m.s.l) and the lowlands <20 m m.s.l or floodplain zone (Koay, 2002). The major rock types in the area are Crocker Formation and Recent sediments. The Crocker Formation cover about 85% of the catchment area and composed mainly of sandstone, siltstone, shale and mudstone (Collenette, 1958). Recent sediments of Late Quaternary age, represented by coastal sands and alluvium, are confined to the lowlands and parts of midlands (Sen, 1997). The area experiences a tropical humid climate with an average annual rainfall of about 2,800 mm.

The catchment drainage pattern can be categorized into two that is dendritic and meandering river. Dendritic rivers can be found in the highland topographic and strongly influenced by the geology of the Crocker Formation. High valley gradients help accelerate the process of erosion. The sediment produced in this zone is the size of the pebble to the size of the block. The lowland or floodplain areas exhibit a single river meander pattern and show active sedimentation and erosion processes on both sides of the river bank which lead to channel instability in the form of bank erosion and avulsion. According to Koay (2002), Tuaran River exhibit a decreased in river length up to 25% within 50 years due to natural hydraulic action and river sand extraction activities.

The study area (Figure 1) is focused at the downstream of Tuaran River bounded within latitude 6^0 10.7′ to 6^0 13.31′ and longitude 116^0 11.8′ to 116^0 14.0′ where river sand is extracted intensively. Those activities have started since early 1990’s (Ngatimin & Ariffin, 1999). In planform the river has the characteristics of a meandering sand-bed river and laterally unstable resulting in point bar and bank erosion. The length of the river studied is about 8 km. Four sites namely as Bend 1, Bend 2, Bend 3 and Bend 4 were selected for the purpose of this study. Bend 1 is considered as a control area where no sand extraction occurred here whereas for the other three sites, the sand extraction activities are active.

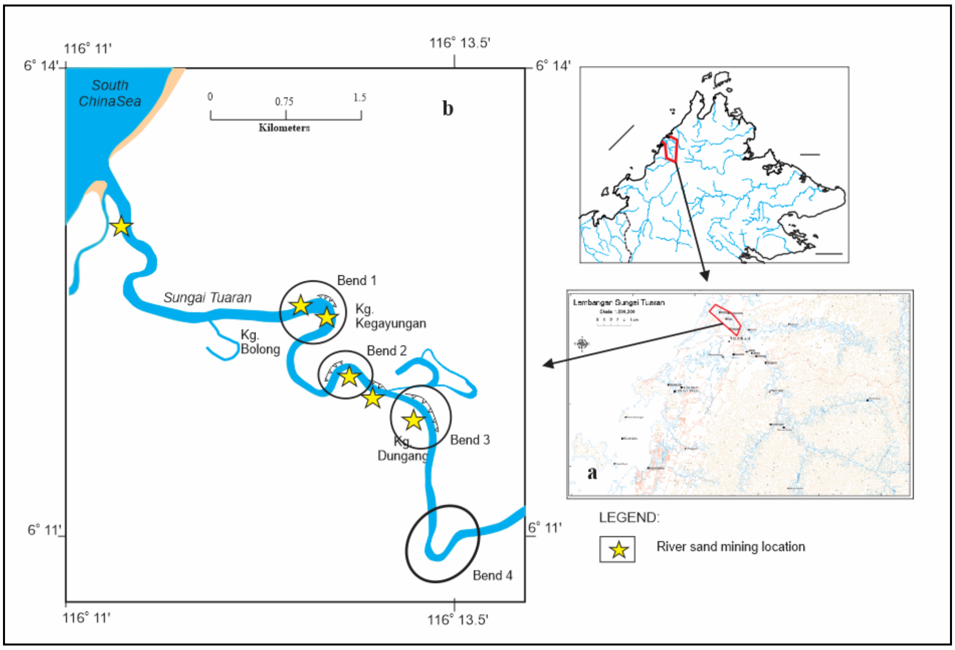

Figure 1. Location of the study area within (a) Tuaran Catchment and (b) downstream of Tuaran River.

METHODOLOGY

Channel Forms

The river channel for the study is a single-thread meandering river located at downstream of Tuaran River. Four single channel bend named as Bend 1, Bend 2, Bend 3 and Bend 4 were selected for analysis. Meander features of interest are the channel width (W) and radius of curvature (Rc). The definitions of the features are as described by Williams (1986) where W is the channel width measured from bank to the opposite bank and Rc is a measure of tightness of an individual meander bend (radius of curvature). Channel planform were digitized at scale 1:10,000 using Google Earth satellite images at different years and georeferenced to WGS 1984 coordinate. Channel width from each bend and year was taken as the mean of several bank inflection points and the radius of curvature were measured based on Williams (1986) definitions. This map were then overlay on JUPEM digital topographic map using GIS software.

Bed Sediment

River bed sediment was sampled in June 2014 in order to acquire comparable bed sediments samples for active and non-active sand extraction reaches. A total of 72 sediment samples were collected using Van Veen grab sampler. Samples were dry and sieved using mechanical Ro-tap shaker and hydrometer method to derived percentages of sand, silt and clay composition. The cumulative frequency curve is then developed by plotting grain size (in phi scale) versus cumulative percent. The phi (φ) values of the following percentile; 5%, 16%, 25%, 50%, 75%, 84% and 95% were read off from the curve. These were used to calculate the mean size of the sediment (Folk & Ward, 1957) using Equation (1).

$$\text{Graphic mean} = \frac{\Phi(16+50+84)}{3} \qquad (1)$$

Data Analysis

Channel stability were evaluated in terms of the ratio of radius of curvature to channel width (Rc/W). Meander migration study at Beatton River by Hickin and Nanson (1984) showed that maximum migration rates occurred at 2.0< Rc/W< 3.0. If Rc/W< 2.0, migration rate per unit channel width declines rapidly to zero at Rc/W ≈ 1 or in other words bank erosion is considerably less. According to Bagnold (1960) Rc/W value less than 2 means larger eddies formation at the inner boundary and this will generates a flow resistance at the outer curve. This process will inhibits bank erosion and meander migration, thereby change the shifting channel process from bank erosion to channel avulsion.

For river sediment data analysis, descriptive statistic, normality tests, Kruskal-Wallis and Mann Whitney tests were employed to assess differences in sediment channel distribution. Kruskal-Wallis test was used to assess variability of sediment mean size at individual cross section; inner bank, outer bank and middle part of the channel whilst Mann Whitney was used to assess the variability of sediment between active and non-active sand extraction areas. Statistical tests were find significant at $\alpha = 0.05$.

RESULT AND DISCUSSION

Table 1 shows data on river meander dimensions and Figure 2 shows the Tuaran River channel planform changes. The highest bend of curvature value is shown in Bend 3 and the lowest is Bend 2. Bend 1 show an increased in bend of curvature value from 1.9 in 2003 to 2.4 in 2016. Bend of curvature for Bend 3 slightly decreased from 3.9 in 2003 to 3.8 in 2014 and increase to 3.9 in 2016. Whereas Bend 2 and Bend 4 respectively decreased from 2.0 to 1.4 and 2.0 to 1.9.

Table 1. Data on river meander dimension by year.

Bend number	Radius of Curvature, Rc (m)				Channel Width, W (m)				Bend of Curvature, (Rc/W)			
	2003	2013	2014	2016	2003	2013	2014	2016	2003	2013	2014	2016
Bend 1	207.5	205.5	205.3	203.0	110.2	86.6	83.2	84.2	1.9	2.4	2.5	2.4
Bend 2	188.6	177.7	156.6	120.0	93.2	102.0	90.1	85.8	2.0	1.7	1.7	1.4
Bend 3	400.6	318.8	305.7	285.5	101.8	83.5	79.8	73.4	3.9	3.8	3.8	3.9
Bend 4	139.7	134.4	130.5	126.2	70.5	71.4	70.6	67.9	2.0	1.9	1.8	1.9

This result shows that at Bend 1 the lateral shifting is now changing from meander cut off process to bank erosion. At Bend 3 the value of bend curvature indicates that bank erosion is the dominant process occurred here since year 2003 till 2016. Bend 2 and Bend 4 however show a decrease in bend of curvature value therefore channel avulsion is the main process occurred here. Bend 2 show a significant lateral shifting to left side of the river and the decreased value of Rc/W indicate that Bend 2 tend to have avulsion process in long term period. Whereas in Bend 4 there is no significant river bank movement (Figure 2) and the river meander dimension not much different from 2003 to 2016 however the bend of curvature is less than 2 therefore channel avulsion process is assumed due to natural river process.

In natural condition, meandering river erode sediment from the outer curve bank and deposit it at the opposite inner bank further downstream. Increase or decrease sediment supply into the river system may induce bed and banks instability and results in dramatic channel readjustments. Based on the observation, it is found that the nature of channel adjustment between non active and active sand extraction areas are similar (Wishart *et al.*, 2008) but sand extraction activity altered river planform at a faster rate than normal river process.

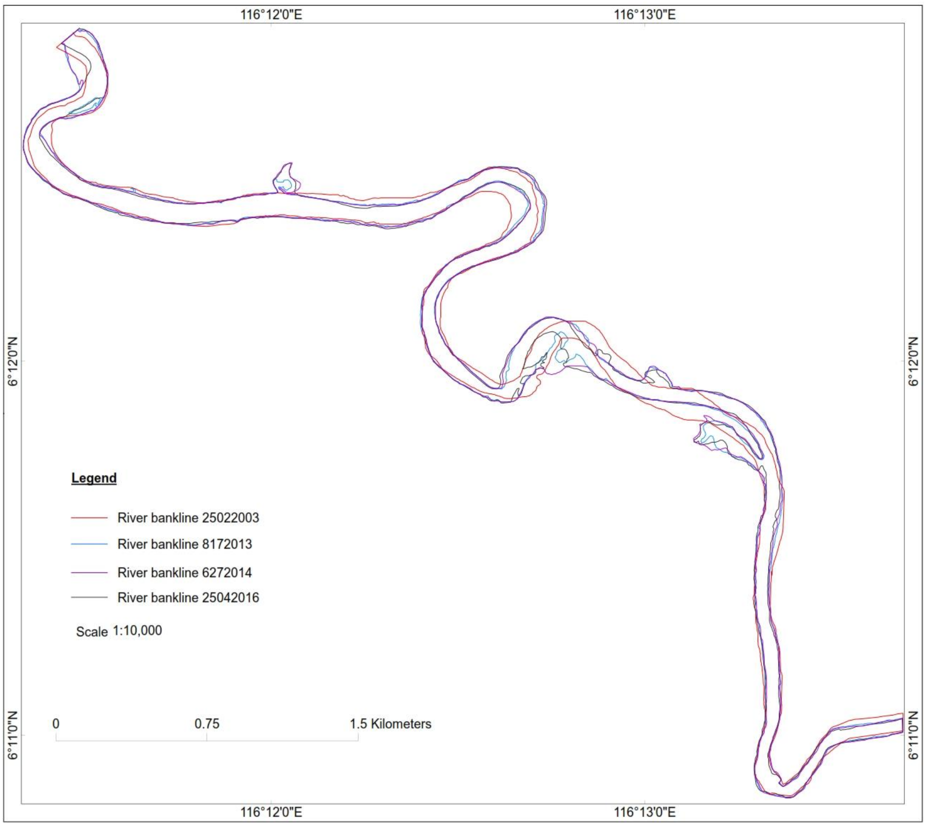

Figure 2. Channel planform changes between 2003 and 2016 derived from Google Earth Image and topography map. River flows from right to left.

Apart from planform changes, the sediment size distribution also differs between those two areas. Figure 3 shows that sand extraction increased mud (silt and clay) in sediment distribution compared to area with no sand extraction. Mann-Whitney test results showed in Table 2 indicate significant differences in mean size distribution between this two areas and mean rank value shows that sediment size in controlled area is coarser compared to active sand extraction area.

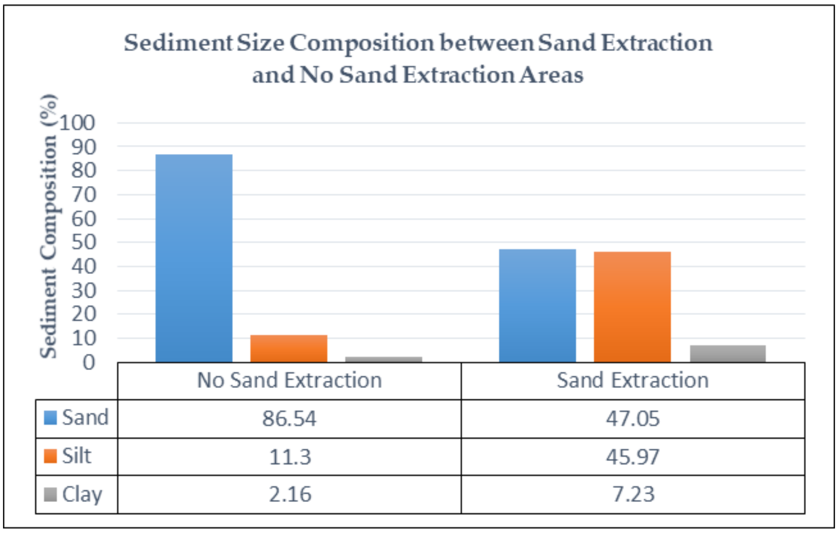

Figure 3. Sediment size distribution between sand extraction and no sand extraction areas.

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Table 2. Comparison of sediments composition between areas.

Sediment	Mean Rank		Mann-Whitney test	
	No sand extraction	Active Sand Extraction	N	p-value
Sand	49.63	23.38	72	< 0.001
Silt	23.35	49.65	72	< 0.001
Clay	23.85	49.15	72	< 0.001

High content of mud can be related to improper washing and screening process carried out at the floodplain area (Figure 4). Fine sediment discharged directly into the river thus lead to high sedimentation further downstream. Fine sediment deposited at the inner bank and this may cause decreased in river width and increased the flow energy. Hence, the channel width is reduced notably in sand extraction area as shown in Table 1.

Figure 4. Photo showing an improper washing and screening process activity on floodplain area contribute to high mud content in the river system especially the sand extraction area.

Kruskal-Wallis test (Table 3) indicates significant differences in mean size distribution between the outer, inner and middle part of the river in the area where no sand extraction occur ($p < 0.05$). Kruskal-Wallis test on mean size distribution where sand extraction occurred show no significant differences ($p > 0.05$). All these extraction and addition directly to the river system have an effect on river profile as well as grain size distribution.

Table 3. Mean size comparisons between parts of the river according to areas.

Area	Mean Rank			Kruskall Wallis test			
	Inner	Middle	Outer	N	d.f.	Chi-square	p-value
No Sand Extraction	19.00	12.5.0	24.00	36	2	7.190	0.027
Active Sand Extraction	17.67	14.08	23.75	36	2	5.164	0.076

CONCLUSION

Channel planform analysis has revealed that sand extraction alter the meander geometry significantly over decade time scale. Removing sediment from the river disrupted the pre-existing balance between sediment supply and transport capacity. In Tuaran River it has been proven that sand removal exceeded the sediment supply therefore induced to lateral channel instability. This channel instability occurred in the form of river bank erosion and sedimentation on the opposite bank. Reduction in channel width due to high sedimentation in inner bank has led to erosion process at the outer bank. In long time period lateral shifting is significant at sand extraction area.

REFERENCES

[1] Ashraf, M. A., Maah, M. J., Yusoff, I., Wajid, A. & Mahmood, K. (2011). Sand mining effects, causes and concerns: A case study from Bestari Jaya, Selangor, Peninsular Malaysia. *Scientific Research and Essays*, **6**(6), 1216-1231.

[2] Bagnold, R. A. (1960). *Some aspects of the shape of river meanders* (No. 282-E). (https://pubs.usgs.gov/pp/0282e/report.pdf). Accessed on 15 October 2017.

[3] Collenette, P. (1958). *The geology and mineral resources of the Jesselton-Kinabalu area, North Borneo. Memoir 6, Geological Survey Department.* British Territories in Borneo, Kuching, Sarawak.

[4] Environmental Protection Department (EPD) (2013). *Management Plan for River Sand Mining in Sg. Tuaran and Sg. Damit, Sabah*. (http://ww2.sabah.gov.my/phb/wp-content/uploads/2013/08/Management-Plan-for-River-Sand-Ming-Sg.-Tuaran-Damit.pdf). Accessed on 15 October 2017.

[5] Folk, R. L. & Ward, W. C. (1957). Brazos River bar: a study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, **27**(1), 3-26.

[6] Frings, R. M. (2008). Downstream fining in large sand-bed rivers. *Earth-Science Reviews*, **87**(1-2), 39-60.

[7] Hickin, E. J. & Nanson, G. C. (1984). Lateral migration rates of river bends. *Journal of Hydraulic Engineering*, **110**(11), 1557-1567.

[8] Koay, M. C. (2002). *Geomorphological study of the Tuaran River System*. Msc Thesis, Universiti Malaysia Sabah, Sabah.

[9] Kondolf, G. M. (1994). Geomorphic and environmental effects of instream gravel mining. *Landscape and Urban Planning*, **28**(2-3), 225-243.

[10] Kondolf, G. M. (1997). PROFILE: hungry water: effects of dams and gravel mining on river channels. *Environmental Management*, **21**(4), 533-551.

[11] Marston, R. A., Bravard, J. P. & Green, T. (2003). Impacts of reforestation and gravel mining on the Malnant River, Haute-Savoie, French Alps. *Geomorphology*, **55**(1), 65-74.

[12] Ngatimin, N. & Ariffin, H. (1999). *Kajian Susulan Kesan Pengambilan Pasir Di Sungai Tuaran, Tuaran Sabah*. No. Laporan SB/SM/99/4. Jabatan Penyiasatan Kajibumi Malaysia.

[13] Padmalal, D., Maya, K., Sreebha, S. & Sreeja, R. (2008). Environmental effects of river sand mining: a case from the river catchments of Vembanad lake, Southwest coast of India. *Environmental Geology*, **54**(4), 879-889.

[14] Rinaldi, M., Wyżga, B. & Surian, N. (2005). Sediment mining in alluvial channels: physical effects and management perspectives. *River Research and Applications*, **21**(7), 805-828.

[15] Sen, S. C. (1997). *Laporan Kemajuan Geologi Kuartenar Kawasan Tuaran Sabah.* No. Laporan SB/QG/97/5. Jabatan Mineral dan Geosains Malaysia, Sabah.

[16] Surian, N., & Rinaldi, M. (2003). Morphological response to river engineering and management in alluvial channels in Italy. *Geomorphology*, **50**(4), 307-326.

[17] Williams, G. P. (1986). River meanders and channel size. *Journal of Hydrology*, **88**(1-2), 147-164.

[18] Wishart, D., Warburton, J. & Bracken, L. (2008). Gravel extraction and planform change in a wandering gravel-bed river: The River Wear, Northern England. *Geomorphology*, **94**(1), 131-152.

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