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Geomorphological and Sedimentological Features of River Sadong, Sarawak, Malaysia

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Abstract - The effect of topography, climate, soil, and geology on River Sadong sediments is related to its geochemistry. Eighteen surface sediments and five core samples were collected in replicates from six sampling sites along River Sadong, Sarawak, Malaysia. The main aim of this study is to describe the geomorphology and sedimentological characteristics of the river sediments. This was achieved by the study of the processes that form the sediments and influence their physical and chemical characteristics. The sediments were analyzed for their sedimentological characteristics. The results indicated that the studied area is enriched with organic matter, and there are no sedimentary structures in its vicinity.

Keywords: geochemistry, geology, geomorphology, River Sadong, sedimentological characteristics, topography

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INTRODUCTION

The River Sadong covers an area of 4,000 km², located between longitudes 1° 14' 0.012" - 1° 34' 0.012" N and latitudes 110° 38.09'.5" - 110° 45' 0" E. It is located in the southern part of Sarawak, Malaysia, about 4.8 km wide and approximately 82.1 km long. This river covers a large area from Serian District to the Samarahan-Asajaya District in Sarawak, Malaysia, and flows largely through the Sadong Basin, southern Sarawak (Bryant, 2003). The river is situated in the northwestern part of Borneo Island, and it is the main source of water for the surrounding com-

munity. It receives a major input of fresh water from upland, transport sediments for several metres then meanders along its path, then flows through the estuary, and finally discharges into the South China Sea. The environments of the River Sadong are characterized by mangrove swamps, abandoned coal mining site, tourism spots, peat swamps, and economic activities such as fishing and agriculture activities. Agriculture is one of the major activities around this river, and rice farming and oil palm plantation are present in some localities around this river. This may lead to a nonpoint source of pollutants due to the use of pesticides, because chemical compounds such

as nutrients and salts can be localized depending on the volume and frequency of their usage.

The objective of this paper is to determine the origin and characteristics of the sediments of River Sadong. This is an attempt to understand the sedimentological characteristics of this river. Studies have been undertaken on some rivers around Kota Samarahan and Asajaya area whereby the heavy metal constituents and their environmental effects were determined (Zulkifley *et al.*, 2015).

The geomorphology of the River Sadong Basin can be described as a forest plain with few banks cultivated with paddy fields and a gradual build-up of floodplain which can be flooded as the season changes (Galloway, 1975; Hart, 1995; Bryant, 2003;). Sadong Basin in Sarawak is characterized as a rainforest type of climate common around the equator, and there is no monsoon season (Lim and Lye, 2003; Esterle and Ferm, 1994). The topography of this area is generally flat around the floodplains of River Sadong which makes them prone to high flooding (Zulkifley *et al.*, 2015). The amount of annual rainfall varies from about 3,000 to over 5,000 mm (DOSM, 2012), thus the land is endowed with vast vegetation. This tropical vegetation provides biomass to accumulating sediments, and its river banks are characterized by forests and cultivated lands. It is mainly a meandering river and its geomorphology is crucial to understanding and interpreting the sediments. The meandering features are very similar, which suggest that the sedimentological behaviour of this river is not complex. It was possible to study the sediment movement and deposition in the river as well as the vertical sequence of river sediments because of the gentle and distinct water table.

Sediments are useful tools in understanding the environment and their physical and chemical characteristics. They are dependent on weathering (Gibbs, 1970; Han and Liu, 2004), geology, drainage pattern, transport, deposition, hydrological factors, geochemical influences (Berner and Berner, 1987), and human activities (Praveena *et al.*, 2008; Sundararajan and Natesan, 2010; Babek *et al.*, 2015; Dhivert *et al.*, 2015). A deeper insight

into the contamination of a water body over a long period of time can be achieved by analyzing river sediments. The most efficient way to understand the sedimentological and geochemical features of a river is by a detailed sampling and laboratory analysis of both surface and core sediment samples (Hahladakis *et al.*, 2013; Maanan *et al.*, 2015a, b).

Figure 1 shows the major soil type is peat that dominated fluvial deltaic system in River Sadong Basin (Lim and Lye, 2003; Zulkifley *et al.*, 2015). The three classes of peat have been identified based on their fiber content namely: fibric, hemic, hemic to sapric, and sapric (Zulkifley *et al.*, 2015). They have various thicknesses and some are as high as 20 m with different colours which may be dark grey, grey, and dark brown, as well as a distinctive odour (Paramanathan, 2011; Huixing *et al.*, 2016).

Geologically, the River Sadong Basin is overlain by over 12 km in depth of Tertiary siliciclastic and carbonate sediments which are divided into various stratigraphic provinces (Kessler, 2009; Madon *et al.*, 2013). Tectonic evolution of the Borneo is believed to be formed by the collision of the Luconia microcontinental block that came from the north into the West Borneo Basement which was part of Sundaland in the south (Hutchinson, 1996; 1989; Madon *et al.*, 2013; Nagarajan *et al.*, 2014). Sadong River lies within the Samarahan District of East Malaysia, in which the area host sedimentary deposit mainly comprises sandstone, schist, and limestone which are Cretaceous to Tertiary in age (Hutchison, 2005). Generally, Sarawak can be divided into four zones based on its geological history, which are: Miri, Sibuan, Kuching, and West Borneo Basement (Liechti *et al.*, 1960; Lam, 1988; Peng *et al.*, 2004). The River Sadong in Samarahan area falls within the Kuching Zone. The Kuching Zone is located towards the southwestern part of Sarawak as shown in Figure 2, which consists of Jurassic to Cretaceous shelf deposits, molasses, and nonmarine deposits on the edge of the West Borneo Basement Complex (Hutchison, 2005).

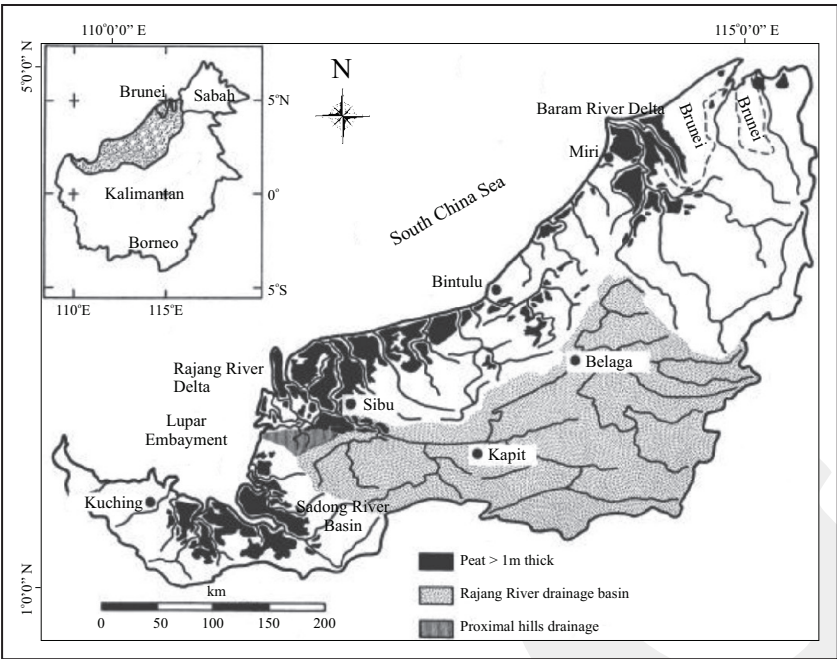


Figure 1. Map showing the geomorphology of Sarawak (Staub *et al.*, 2000).

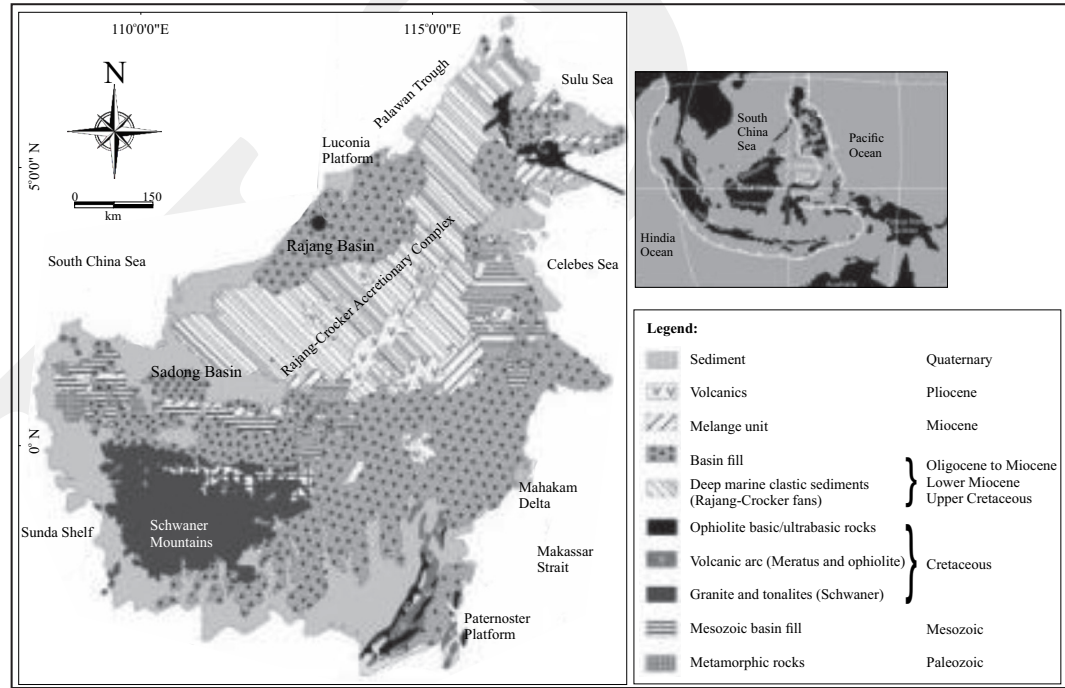


Figure 2: Geology of the Borneo Basin (after Hall *et al.*, 2008 and Nagarajan *et al.*, 2014).

MATERIALS AND METHODS

Studied Area and Sample Location

The samples were collected on August 2016 and March 2018 with a total of six sampling sites for surface sediments and five sampling sites for

core sediments (Table 1) within River Sadong, Kota Samarahan, Sarawak, Malaysia. A total of eighteen undisturbed surface sediment samples and five core samples with their replicates were taken using a Wildco stainless steel grab sampler and corer at different stations of the river (Figure

Table 1. Sampling Location at River Sadong, Sarawak

Stations	Geographical Coordinates	Locality	Major Activities
ST1	N01°30'51.0", E110°44'24.6"	Sadong Jaya	Fishing, small jetty
ST2	N01°27'19.4", E110°41'08.1"	Sungai Buloh	Ferry service, bridge
ST3	N01°14'49.3", E110°41'06.6"	Simunjan	Fishing and small jetty
ST4	N01°14'38.5", E110°40'42.5"	Gedong	Residential area (potential tourist attraction)
ST5	N01°14'42.1", E110°38'09.5"	Sebemban	Farming, Oil Palm Plantation, Residential area
ST6	N01°14'49.3", E110°33'58.0"	Serian	Residential area

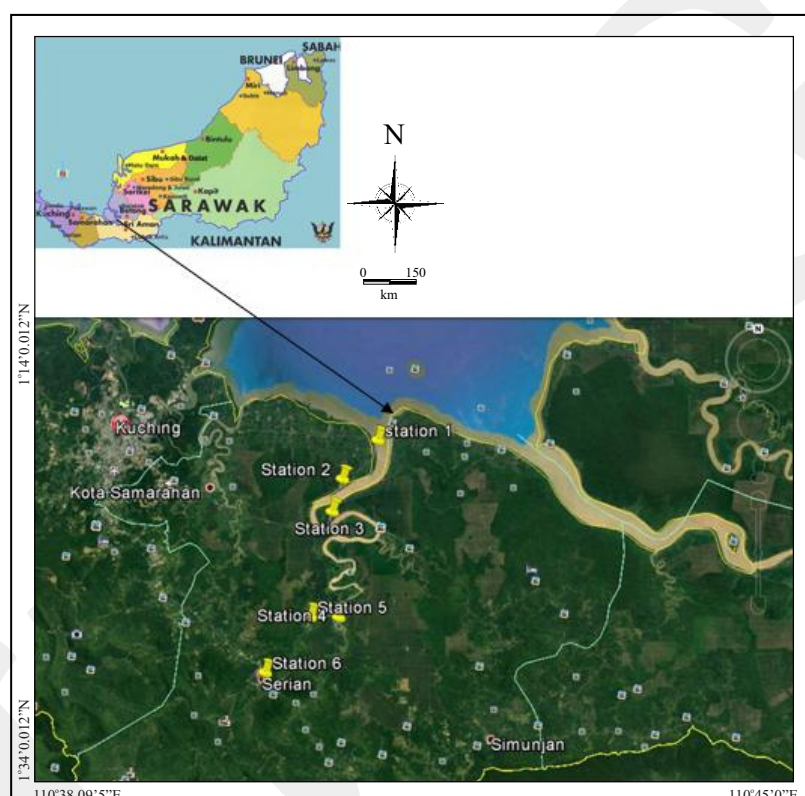


Figure 3. Location map of the River Sadong (inset map of Sarawak).

3). The coordinates of the sampling sites were recorded by Global Positioning System (Table 1). During the sampling, the weather conditions were dry with calm winds, shiny with no rain, and the ground temperature was approximately 27°C.

Sample Preparation

Surface samples and core sediments were collected from the sampling sites at River Sadong and placed in plastic bags. Each core sediment was sliced at 2.5 cm interval and then stored in a cooler box. The samples were transported to

the laboratory and stored at -20°C until further analysis. The sediments were air dried in the laboratory at room temperature for 72 hours, and then pulverized into powder form by using a porcelain mortar and pestle, then sieved vigorously to determine the particle size (Sany *et al.*, 2013).

Instrumental Analysis

The particle size was determined using a series of sieves, with the 63µm stainless steel aperture was the least size. The moisture content, total organic matter (TOM), and ash content were

determined using ignition loss. The moisture content was determined by drying the sediment in an oven. Two gram of sediment sample was heated in the furnace at 100°C for two hours and for 550 °C for five hours to determine the total organic matter and ash content respectively which is expressed as a percent of the oven dry mass (ASTM D2974). This was carried out using Ney VULCAN D -550 furnace oven in the Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, Malaysia.

RESULTS AND DISCUSSION

The sediments from Station 2 (Table 2) are dark grey with many dark particles, which may be attributed to the presence of hydrocarbon content (oil) in the sediment due to high vehicular movements and ferry service in the area (Walling, 2006). The sediments at Station 5 are dark grey with black twigs and dried leaves, while the sediments at ST4 (Table 2) are dark grey with black plant assemblages which are present even at deeper depths. The dissolved and suspended load (with few microns in diameter) in River Sadong was formed due to weathering (Staub and Esterle, 1993; Scott, 1985). The physical weathering of rocks and soils are important processes in the geochemical cycle of this river.

Most of the sediments were derived from dissolved carbonate rocks, few silicate rocks, and the extensive peat soil that surrounds the area (Li *et al.*, 2007). The important physical characteristics

of sediment are the texture, structure, and colour (Lewis, 1984). River Sadong is characterized by a floodplain, estuary, as well as a coastal plain with tidal currents (Postma, 1960). The surrounding towns include Sadong Jaya, Sungai Buloh, Simunja, Gedong, and Sebemban (Table 2). The floodplain covers a large area in Gedong which are well drained by the River Sadong and smaller river channels (Bryant, 2003).

The bed load which represent the coarser fraction formed by mechanical weathering (Gupta *et al.*, 2011) which are part of the residual products of the rocks were absent, whereas the presence of twigs and leaves are due to vegetation, and dark particles on sediments maybe due to fertilizers and vehicular emissions. The sediments have high storage capacities for contaminants due to their small surface area. Both surface and core sediment samples are useful in environmental studies (Karbassi and Shankar, 2005; Geetha *et al.*, 2008; Al-Juboury, 2009; Chibunda, 2009; Ahmad *et al.*, 2010; Nobi *et al.*, 2010; Tatone *et al.*, 2016).

There are no obvious sedimentary structures in River Sadong, because most of the sediments are fine-grained (Table 3), comprising mainly silicate minerals (quartz and clay minerals) and biogenic components (organic matter) (Rainey *et al.*, 2003; Paramanathan, 2011). The Sadong River is characterized by fluvial, floodplain, and deltaic depositional systems. The sediments accumulate in both continental (terrestrial) and marine (sea) environments (Table 3). The estuaries and coastal zones are the main channels between land and ocean (Masood *et al.*, 2014; 2016).

Table 2. Physical Characteristics of Sediments at River Sadong, Sarawak

Stations	Locality	Colour	Type of Sediment
ST1	Sadong Jaya	dark grey	silty clay
ST2	Sungai Buloh	dark grey with black particles	silty clay
ST3	Simunjan	dark grey	clay
ST4	Gedong	dark grey with black plant assemblages	silty clay
ST5	Sebemban	dark grey with black twigs	silty clay
ST6	Serian	dark grey	sandy clay

Table 3. Types of Depositional Environment and Sediment in River Sadong

Environment	Agent of Transportation	Depositional Environment	Sediment Type
Fluvial (Stations 1,2)	Wind and moving water	Fluvial and alluvial	Sand, silt, and OM*
Transitional (Stations 3,4,5)	Slow moving water, tidal current	Floodplain and deltaic	Silt, clay, and OM*
Fluvial (Station 6)	Moving water, tidal current	Fluvial	Sand, clay, mud, and silica mud

OM*: organic matter

The meandering feature of River Sadong along Station 3 shows little diversity, which is useful in understanding the sedimentological behaviour of this river (Table 3). The seasonal variation in the discharge of sediments is the primary control of drainage patterns in this river, because the amount of transported sediments vary during the dry and wet seasons (Gastaldo and Staub, 1999; Staub *et al.*, 2000).

Sedimentology has an increasing importance in environmental pollution studies. Sediments have different textures and structures depending on the internal arrangement of the grains (Ratha and Sahu, 1994; Kashani *et al.*, 2016). Sediments accumulated in this river were caused by the transportation of siliclastic sediments from the upland drainage basin (Stations 5 and 6) to the floodplain area (Stations 3 and 4) towards the fluvial area (Stations 1 and 2), and flows to the ocean which transports reworked and deposited sediments into the South China Sea (Tongkul, 1996; Kessler 2009).

River sedimentation is an active process in sediments whereby new sediments are constantly brought in, while others are transported by river current and tidal actions. Therefore, this is useful in the environmental assessment of the river. Changes in river flow regimes have the potential to affect the patterns of erosion and deposition within the river channels and estuaries (Salomons, 1997; Gibson *et al.*, 2015). This affects the chemical components of the river, because they are controlled by natural factors (geology, biological, and geomorphology) and anthropogenic activities (land use and industrial waste) (Syvitski *et al.*, 2005; Shan *et al.*, 2013). As the sediment is transported, the fluctuations in the mineralogical components affect the concentration of chemi-

cal species (Masood *et al.*, 2016). Whereas the investigation of sedimentary features can be used to reveal the input history of materials derived from the terrestrial environment (Calvert *et al.*, 2001; Glasby *et al.*, 2004; Naimo *et al.*, 2005; Wei *et al.*, 2006;). This helps to understand the environmental impact on this river system.

River Sadong is the typical of rivers in the tropics which are prone to flooding and have an increasing risk of soil erosion and sediment influx due to increasing frequency of rainfall (Staub *et al.*, 2000; Gupta *et al.*, 2011). The fluvial geomorphology indicates that the river is sensitive to climatic changes and fluctuations in sediment delivery which are often more intense than changes in hydrological regime (Al-Masri *et al.*, 2002; Arnell *et al.*, 2015).

The moisture content has a similar range in the top core samples and increases downwards to the middle, and then varies considerably toward the lower layer in all locations (Table 4). The highest value for moisture content occurs in the upper layer between 0 - 7.5 cm. Most geochemical changes in rivers take place at or close to the sediment/water boundary (Sundararajan and Natesan, 2010). Figure 4 present the vertical profile of moisture content of core sediments from River Sadong.

The ash content in the sediments of River Sadong as shown in Table 5 indicates the removal of organic content. The vertical profile of ash content is shown in Figure 5.

The studied area is enriched with organic matter on a moderate range (Table 6). Figure 6 present the vertical profile of organic matter contents. The mass vegetation around the river banks may account for the high organic matter (Keil *et al.*, 1997). The sediments in Sadong River

Table 4. Moisture Content of Sediments from Six Stations in Sadong River

Sample ID	Depth (cm)	Moisture Content (%)					
		Stations					
		ST1	ST2	ST3	ST4	ST5	ST6
A	0.0 - 2.5	46.5	44.5	33.5	41.5	45.0	48.0
B	2.5 - 5.0	47.5	43.5	38.5	38.0	39.0	36.0
C	5.0 - 7.5	48.5	36.5	39.0	38.0	37.0	37.5
D	7.5 - 10.0	48.0	46.5	39.5	37.0	38.5	36.5
E	10.0 - 12.5	47.0	43.5	38.5	32.0	41.5	36.5
F	12.5 - 15.0	39.0	42.0	36.0	46.0	47.0	37.5
G	15.0 - 17.5	38.5	39.0	38.0	36.5	48.0	39.5
H	17.5 - 20.0	40.0	44.5	26.5	43.0	42.0	36.5
I	20.5 - 22.5	40.0	43.5	-	-	43.0	34.5
J	22.5 - 25.0	38.5	32.5	-	-	44.5	37.5
K	25.0 - 27.5	42.0	35.5	-	-	48.0	43.5
L	27.5 - 30.0	40.5	38.0	-	-	41.0	39.5
M	30.0 - 32.5	42.5	44.5	-	-	-	32.5
N	32.5 - 35.0	40.5	43.5	-	-	-	32.0
O	35.0 - 37.5	45.0	-	-	-	-	36.0
P	37.5 - 40.0	47.5	-	-	-	-	36.5
Q	40.0 - 42.5	45.5	-	-	-	-	27.5
R	42.5 - 45.0	50.0	-	-	-	-	29.5

Table 5. Ash Content of Sediments from Six Stations in River Sadong

Sample ID	Depth (cm)	Ash Content (%)					
		Stations					
		ST1	ST2	ST3	ST4	ST5	ST6
A	0.0 - 2.5	91	93	94	87	93	90
B	2.5 - 5.0	92	94	90	95	93	93
C	5.0 - 7.5	92	94	94	94	93	94
D	7.5 - 10.0	95	87	90	98	91	95
E	10.0 - 12.5	96	87	91	98	91	94
F	12.5 - 15.0	93	86	91	95	90	96
G	15.0 - 17.5	91	92	92	97	91	94
H	17.5 - 20.0	97	94	90	95	93	94
I	20.5 - 22.5	95	93	-	-	96	96
J	22.5 - 25.0	88	96	-	-	91	98
K	25.0 - 27.5	93	91	-	-	90	98
L	27.5 - 30.0	92	93	-	-	92	99
M	30.0 - 32.5	94	-	-	-	-	98
N	32.5 - 35.0	94	-	-	-	-	96
O	35.0 - 37.5	95	-	-	-	-	97
P	37.5 - 40.0	92	-	-	-	-	93
Q	40.0 - 42.5	96	-	-	-	-	95
R	42.5 - 45.0	94	-	-	-	-	95

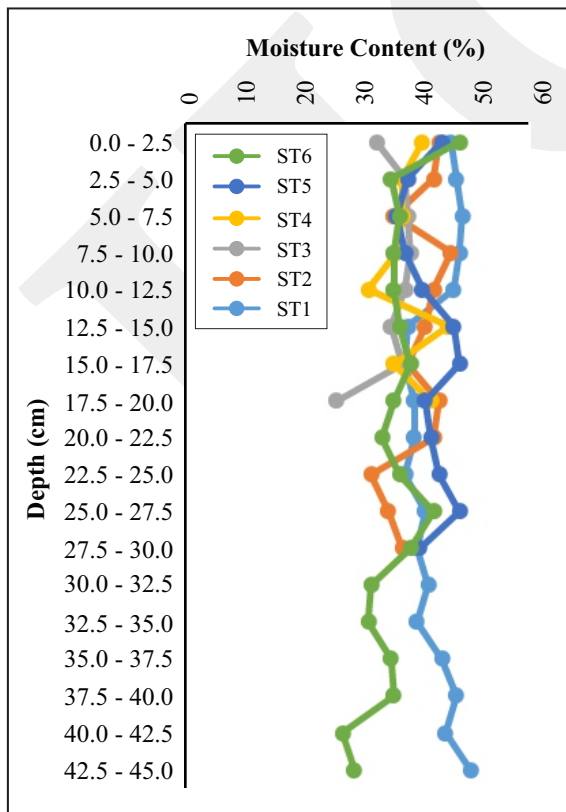


Figure 4. Vertical profile of moisture content of core sediments from Sadong River.

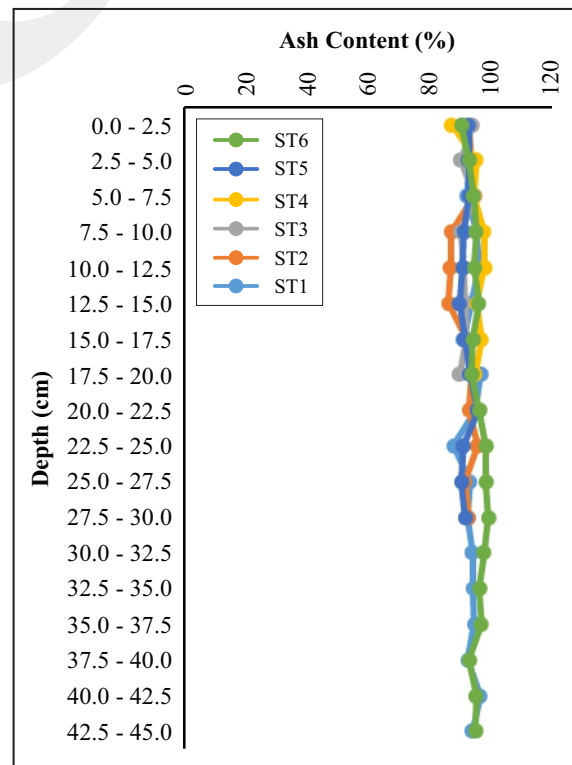


Figure 5. Ash content of core sediments from River Sadong.

Table 6. Organic Matter Content of Sediments from Six Stations in River Sadong

Sample ID	Depth (cm)	Organic Matter (%)					
		Stations					
		ST1	ST2	ST3	ST4	ST5	ST6
A	0.0 - 2.5	9.3	7.2	6.0	12.8	7.3	9.7
B	2.5 - 5.0	7.6	6.2	9.8	4.8	7.3	7.0
C	5.0 - 7.5	7.8	5.5	5.7	5.6	7.1	5.6
D	7.5 - 10.0	4.8	13.0	9.9	2.4	8.7	4.7
E	10.0 - 12.5	3.8	13.3	8.9	2.2	9.3	5.5
F	12.5 - 15.0	6.6	13.8	8.6	4.6	10.3	4.0
G	15.0 - 17.5	8.9	8.2	8.0	3.1	8.7	5.8
H	17.5 - 20.0	3.3	6.3	10.2	5.3	6.9	6.3
I	20.5 - 22.5	5.0	7.1	-	-	4.4	3.8
J	22.5 - 25.0	12.2	4.4	-	-	9.0	1.6
K	25.0 - 27.5	6.9	8.5	-	-	9.6	1.8
L	27.5 - 30.0	7.6	7.3	-	-	8.5	0.8
M	30.0 - 32.5	6.1	-	-	-	-	2.2
N	32.5 - 35.0	5.9	-	-	-	-	3.7
O	35.0 - 37.5	5.5	-	-	-	-	3.1
P	37.5 - 40.0	7.6	-	-	-	-	7.1
Q	40.0 - 42.5	3.7	-	-	-	-	4.8
R	42.5 - 45.0	6.0	-	-	-	-	4.9

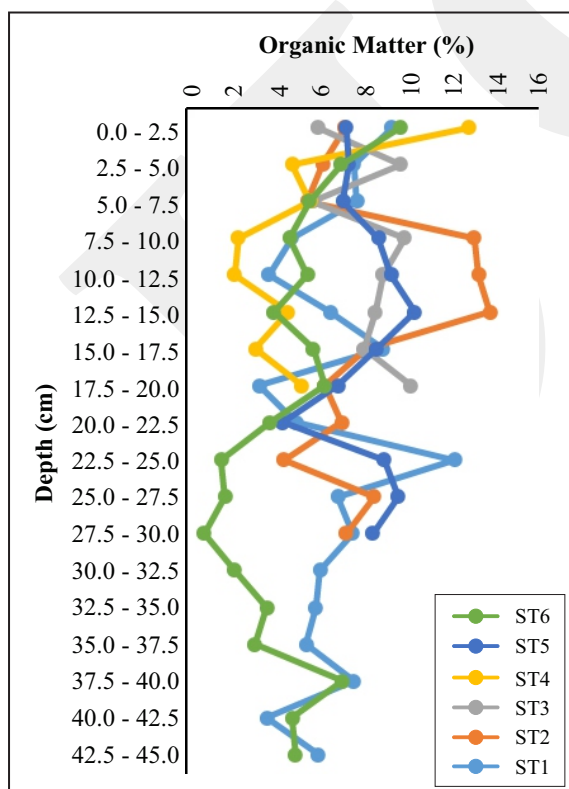


Figure 6. Vertical profile of organic matter of core sediments from River Sadong.

acts as sinks and maybe sources of contaminants in river systems because of their variable physical and chemical properties (Sundararajan and Natesan, 2010).

CONCLUSIONS

This study gives an understanding of the sedimentological and geomorphological characteristics of Sadong River. Sediments in all sampling sites contain mostly fine-grained particles. The sediment particles comprise clay, silt, and organic matter. The river sediments were derived mainly from weathered rocks and soils which were transported and deposited by wind and water, from atmosphere as dust particles, and human activities.

The increase in population and urbanization has impacted the area as well. Deforestation was also observed in some areas in order to extend the oil palm plantation. This has made some areas prone to flooding causing loss of flora and fauna. Some trees are left on the ground to decompose which may account for the presence of plant remains such as dried leaves and twigs in some areas.

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