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Review of the Sedimentological and Geochemical Approaches for Environmental Assessment of River Sadong, Samarahan-Asajaya District Sarawak, Malaysia

Omolayo Ajoke Omorinoye*(**)†, Zaini Bin Assim*, Ismail Bin Jusoh*, Naseer Inuwa Durumin Iya*(***) and Isaac John Umaru*(****)

*Faculty of Resource Science and Technology, Universiti Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia

**Department of Geology and Mineral Sciences, Faculty of Physical Sciences, University of Ilorin, P.M.B. 1515, Ilorin, Nigeria

***Department of Chemistry, Federal University Dutse, Jigawa State, Nigeria

****Department of Biochemistry, Federal University Wukari, Taraba State, Nigeria

†Corresponding author: Omolayo Ajoke Omorinoye

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ABSTRACT

This paper presents an overview of the implication of geomorphology and sedimentology on the chemical characteristics of sediments of River Sadong, Malaysia. There is limited published work on the effect of topography, climate, soil and geology on the sediments lying in the River Sadong. Studies have been undertaken around Kota Samarahan and Asajaya areas whereby some heavy metal constituents and their environmental effects were determined. The study entails the description of the depositional processes alongside with physical and geochemical changes, without neglecting natural and anthropogenic effects.

INTRODUCTION

The River Sadong covers a large area of the Samarahan-Asajaya district in Sarawak, Malaysia (Fig. 1). The river flows largely through the Sadong Basin, its length is about 40km in Samarahan, Southern Sarawak (Bryant 2003). It receives a major input of freshwater from upland (Serian), transports sediments over several metres, then meanders along Satubong, which flows through the floodplain at Gedong and finally makes its way into the ocean in the South China Sea. The environs of river Sadong are characterized by extensive economic and industrial resources such as fishing, mangrove swamps, abandoned coal mining sites, tourism spots and peat swamps. At about 20km up this river, it bifurcates towards the east at Simunja which is characterized by an isolated mountain where coal was mined in the 19^{th} and 20^{th} century (Bryant 2003).

Sediments can be defined as the solid particles that settle on the earth surface either on land or in rivers and oceans. They consist of rock fragments, sand, silt, clay, dissolved organic matter and remains of plants and animals. Rivers are greatly affected by population growth, increased industrialization and urbanization (Babek et al. 2015, Dhivert et al. 2015). River sediments are useful tools in understanding the environment and their physical and chemical characteristics are dependent on weathering, geology, drainage pattern, transport, deposition, hydrological factors, geochemical influences and human activities (Sundararajan & Natesan 2010, Praveena et al. 2008). A detailed insight into pollution and contamination of a river over a long period of time can be achieved by the analysis of river sediments. Generally, rivers are affected by flows of surface and groundwater from the land and large rivers flow into the sea through estuary. The chemical properties of a river are dependent on the materials dissolved in the water or metals and ions present in the sediments (Arnell et al. 2015, Sundararajan et al. 2009, Nesbitt & Young 1996).

The consequences of human development due to population growth, increased industrial zone, agricultural activities and urbanization have geochemical effects on water bodies, especially rivers (Tatone et al. 2016, Mohiuddin et al. 2010). The most efficient way to understand the sedimentological and chemical features of a river is by a detailed sampling and laboratory analysis of both surface and core sediment samples. The management and protection of the natural environment of the river can be inferred from the useful application of indicators in geochemical

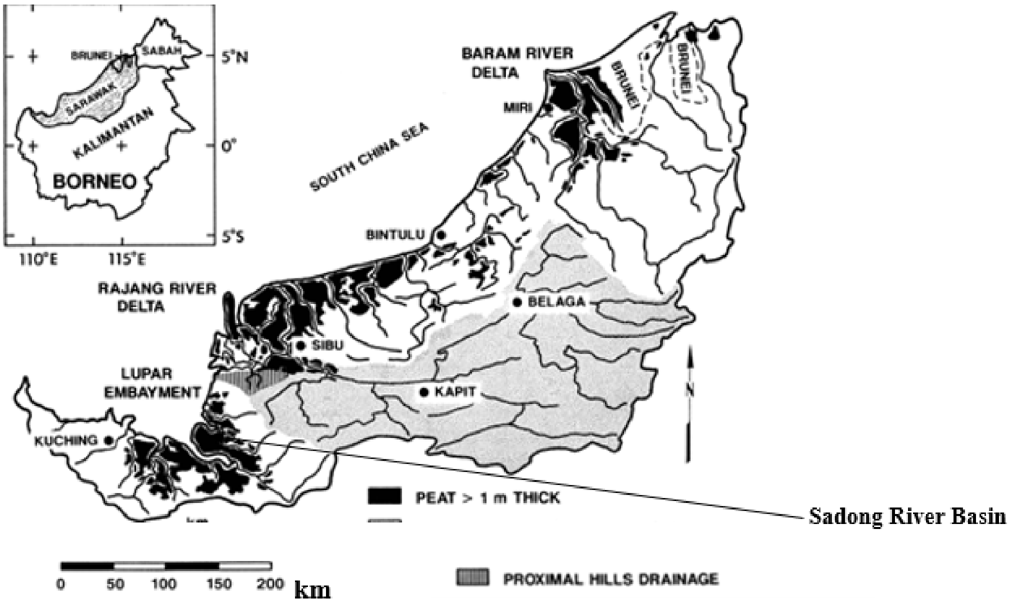

Fig. 1: The map showing the geomorphology of Sarawak (Staub et al. 2000).

data and results (Babek et al. 2015, Masood et al. 2014, Harikumar et al. 2009).

STRATEGIES IN ENVIRONMENTAL ASSESSMENT

River sedimentation is an active process because sediments are often transported and re-worked in the river system and there is a possibility of industrial contamination because fresh (new) sediments can be deposited while others are carried along by tidal actions and river currents (Gibson et al. 2015). The fluctuations in river flow regimes have the ability to affect the patterns of erosion and deposition within the river channels and estuaries (Salomons 1997). The chemical components of rivers such as the heavy metals and trace metal contents are controlled by natural factors, i.e. geologic, biological as well as geomorphologic and anthropogenic activities such as land use and industrial waste (Shan et al. 2013).

Fluvial geomorphology and geochemical studies indicate that rivers are sensitive to climatic changes and fluctuations in sediment delivery (Arnell et al. 2015). The river Sadong is typical of rivers in the tropics, which are prone to flooding due to an increased risk of erosion and sediment influx because of frequent rainfall (Gupta et al. 2011, Staub et al. 2000). The top portion of river sediment, which is the water/sediment boundary, has significant characteristics.

Sediments have the capacity to retain and absorb and release heavy metals in the system. Sediment cores are important when compared to surface samples because they often overcome and retain environmental processes such as climate change, floods, storms, landslides, etc. The concentration of chemical species is related to changes in the mineral assemblages (Masood et al. 2016) whereas the investigation of sedimentary features can be used to reveal the history of input of materials derived from the terrestrial environment (Wei et al. 2006, Naimo et al. 2005, Glasby et al. 2004, Calvert et al. 2001). This helps to understand the environmental impact on river systems.

PHYSIOGRAPHIC SETTING OF THE RIVER SADONG BASIN

The River Sadong is located within the southern part of Sarawak, Malaysia. It covers an area of about 4000km^2 between longitudes 1°1'0.012" and 1°34'0.012" North and latitudes 110°38.0'9.5" and 110°45.0' East. The width is about 4.8km and its length is about 82.1km (Bryant 2003). This river covers a large area from the Serian district to the Samarahan-Asajaya district in Sarawak, Malaysia. It lies in the northwestern part of the Borneo Island and it is the main source of water supply to surrounding community. The major input of freshwater is from upland and flows downstream through the estuary and ends up at the ocean. The alluvial valley is in Simunja and Asajaya districts that are well drained by the River Sadong and smaller river channels.

GEOMORPHOLOGY OF THE RIVER SADONG BASIN

The environs of this river can be described as a forest plain

Table 1: The geomorphology of Sarawak.

Relief	Cities	Topographic Features
Alluvial Coastal (Staub et al. 2000)	Kuching, Sibu, Sarikei, Lundu forest and tidal inundation	Peat soil, mangrove and nipa vegetation, swamp
Undulating Interior (Bryant 2003)	Satubong, Simunja, Asajaya, Serian interior mountainous region	Moderately rugged terrains, fast flowing rivers
Mountainous (Nagarajan et al. 2014)	Bintulu, Sri Aman, Betong, Miri rapids	Thick forest, fast flowing rivers with numerous

Table 2: The types of depositional environment and sediment in River Sadong.

Environment	Agent of Transportation	Depositional Environment	Sediment Type
Alluvial	Moving water	Fluvial and alluvial	Sand, silt and OM*
Transitional	Moving water, tidal current	Floodplain and deltaic	Silt, clay and OM*
Marine	Moving water, tidal and ocean current	Sea	Sand, clay, carbonate mud and silica mud

OM*- Organic matter

with few cultivated banks with paddy fields and a gradual formation of the flood plain, which can be flooded as season changes (Bryant 2003). The Sadong basin has a rainforest type of climate and there is no distinct monsoon nor dry season (Lim & Lye 2003, Esterle & Ferm 1994). The topography of this area is generally flat around the flood plains of Batang Sadong, which makes them prone to high flooding (Zulkifley et al. 2015, Staub & Esterle 1994).

The equatorial rainfall varies from 3000 to over 5000mm per year (DOSM 2012), thus endowing the land with vast vegetation and some perennial river channels. This provides biomass and accumulating sediments of both tropical and riparian vegetation, which is composed of marine to brackish water fed mangroves (Table 1). The major soil type in the environs is the extensive peat that dominated the fluvial deltaic system in Sadong river basin (Zulkifley et al. 2015, Lim & Lye 2003, Staub & Esterle 1993). The three classes of peat have been identified based on their fibre content namely: fabric, hemic, hemic to sapric and sapric (Zulkifley et al. 2016). They have varied thickness and some are as high as 20m with different colour, which may be dark grey, grey and dark brown as well as have a distinctive odour (Huixing et al. 2016, Paramananthan 2011).

GEOLOGICAL FEATURES OF RIVER SADONG ENVIRONS

The tectonic evolution of the Borneo is believed to be formed by the collision of the Luconia microcontinental block in the north and the West Borneo Basement, which was part of the Sundaland in the south (Madon 2013). This area hosts sedimentary deposit of Cretaceous to Tertiary age mostly made up of sandstone, schist and limestone (utchinson 2005). The main constituent of most sediments from these rocks are inorganic mineral material because the crustal rocks are their main source (Hutchison 2005).

Generally, there are four zones in Sarawak based on its geologic history. These are: Miri, Sibu, Kuching and West Borneo Basement. The Samarahan area falls within the Kuching zone. This zone lies in the southwestern part of Sarawak and consists of Jurassic to Cretaceous shelf deposits, molasses as well as non-marine deposits at the edge of the West Borneo Complex (Hutchinson 2005, Tongkul 1996). The Sadong River Basin is overlain by over 12km of siliciclastic and carbonate rocks, which are Tertiary in age and are distributed in various stratigraphic provinces (Madon et al. 2013, Kessler 2009, Peng et al. 2004, Liechti et al. 1960). The dissolved and suspended load (with few microns in diameter) in River Sadong are from weathering of these rocks. The mechanical and chemical weathering of soils and rocks are important processes in the geochemical cycle of different elements in this river (Gupta et al. 2011).

SEDIMENTOLOGICAL CHARACTERISTICS OF RIVER SADONG

Sedimentology is of increasing importance in environmental pollution studies; sediments have different textures and structure depending on the internal arrangement of the grains (Kashani et al. 2016, Ratha & Sahu 1994). This river is characterized by fluvial, floodplain and deltaic depositional systems (Staub et al. 2000). Sediments accumulate in both the continents (terrestrial) and sea (marine) environments (Table 2), the coastal zones and estuaries are the main channels between land and ocean (Masood et al. 2016, 2014). They accumulate in the river by the transportation of

Table 3: The sedimentological characteristics of some rivers.

Location	Grain Size (sand, silt, clay)	Organic Carbon
Upper Loire, France [a]	2% - 49%	0.02% - 4.9%
East coast of NSW, Australia[b]	1% - 56%	5 mg/g - 90 mg/g
Southeast Coast of India[c]	0.2% - 98.57%	n.d
Kemaman Estuary, Malaysia[d]	2.9% - 79%	n.d

Source: [a]Dhivert et al. (2015); [b]Hettiarachchi et al. (2016); [c]Sundarajan & Natesan (2010); [d]Shahbudin (2008)

siliciclastic sediments from the upland drainage basin downwards the fluvial area towards the floodplain area. The river through the deltaic system transports reworked and deposited sediments into the sea. The meandering feature of Sadong river shows little diversity. The river seasonal variation in discharge of sediments is primarily controlled by the drainage pattern because the amount of sediments transported varies during the dry and wet seasons (Staub et al. 2000). The organic matter constituents are predominantly plant remains while the sediments are mostly clay and silt.

Due to the small surface area of sediments, they have a high storage capacity for contaminants. This makes both, surface and core sediment samples very useful in environmental studies (Tatone et al. 2016, Ahmad et al. 2010, Al-Juboury 2009, Chibunda 2009, Geetha et al. 2008, Karbassi & Shankar 2005). They are influenced by interactions of physical, chemical and biological processes which trap significant quantities of both natural and anthropogenic constituents (Nobi et al. 2010, Pekey 2006).

The important sediment characteristics in this area are the texture, structure and colour (Table 3). There are no obvious sedimentary structures such as mud cracks and fractures, this is because most of the sediments are fine grained and often wet. They are composed mainly of silicate minerals (quartz and clay minerals) and biogenic components (organic matter) (Paramananthan 2011, Rainey et al. 2003). In previous studies, the most common method for the comparison of sediment metal concentrations with background levels was to compare the most recent metal levels with their concentrations in standard earth materials (Turekian & Wedepohl 1961) such as a shale (a sedimentary rock) or the average value of the earth crust (Taylor 1964).

GEOCHEMICAL CHARACTERISTICS OF SEDIMENTS

Lithologic contribution of heavy metals in river is used as a background value in sediments, while the significant difference in concentration of a known heavy metal in sediments is attributed to a point source (Forstner & Whitmann 1979). The geochemistry of river Sadong is related to both the stable and tectonic active regimes caused by the fast weathering process of biogenic and inorganic carbonates (Singh et al. 2005, Huy et al. 1998) as well as the slow dissolution of alumino-silicate with minor contribution from the basement rocks (Han & Liu 2004, Berner & Berner 1987, Meybeck 1986, Gibbs 1970). The geochemical fluctuations of rivers globally are greatly influenced by trapped sediments, dissolved loads and nutrients (Li et al. 2017, Walling 2006, Syvitski et al. 2005). The changes in climatic conditions (Karbassi & Amirnezhad 2004), accumulation and mobilization of trace elements affect the river. Sediments act as sink of contamination in River Sadong (Al-Juboury 2009, Priju & Narayana 2007, Marchand et al. 2006). Natural concentration of some heavy metals in different media is dependent on different factors (Table 4).

At the basin scale, the spatial distributions of metallic pollutants are mainly controlled by the settling capacity of 63 μm sized sediments which are fine-grained (Mohiuddin et al. 2010, Harikumar et al. 2009, Akcay et al. 2003). These heavy metals from both natural and anthropogenic sources are accumulated in river sediments (Kalloul et al. 2012, Zourarah et al. 2009, 2007). For the study of river pollution, heavy metals (Al, As, Cd, Co, Cr, Cu, Fe, Ni, Pb and Zn) have been strongly recommended for use by international organizations (Maanan et al. 2015a, b). Their distributions, toxicity (Sakan et al. 2009, Szefer et al. 1996, Loring 1978) and non-biodegradable nature (Nair & Sujatha 2013, Sany et al. 2013, Praveena et al. 2008, Clement et al. 1995) are of great interest.

ORIGIN OF HEAVY METALS IN RIVER SEDIMENTS

All heavy metals occur naturally and their concentrations have increased significantly in natural rivers due to agricultural and industrial activities. The heavy metals of River Sadong originate from both natural processes and anthropogenic activities (Xin et al. 2014). This include geological, geochemical and biological processes in the earth crust (Taylor & McLennan 1995). Others include wind- blown dusts, eroded soils and sediments which put huge amounts of solid material into this river (Scott 1985). Unlike geological sources, living things have a major role in the exchange of gases within the atmosphere and hydrosphere. Processes such as climate change, natural disasters including floods, storms, landslides, earthquakes, volcanoes, tsunamis and forest fires emit enormous quantities of organic compounds and heavy metals.

Moreover, river water chemistry is mostly dependent on precipitation, mineral weathering and evaporation-crystal-

Table 4: Natural concentration of heavy metals in different media (mg/kg dry weight) (Hakanson 1980)

	Igneous rocks	Sedimentary rocks	Soil	Sea water	Freshwater	Land plants	Land animals	Lakes
Ag	0.07	0.05	0.1	< 0.0001	0.00013	0.06	0.006	d” 1
Al	82000	80,000	71,000	< 0.0001	0.24	500	d” 100	26,000
As	1.8	d” 13	6.0	0.0026	0.0004	0.2	d” 0.2	8.6
Cd	0.2	d” 0.3	0.06	0.0001	< 0.08	0.6	d” 0.5	0.58
Co	25	d” 20	8.0	< 0.0001	0.0009	0.5	0.03	18.5
Cr	100	d” 100	100	0.00005	0.00018	0.23	0.075	48.7
Cu	55	d” 50	20	0.003	0.01	14	2.4	28.7
Fe	56,300	d” 50,000	38,000	< 0.0001	0.67	140	160	26.7
Hg	0.08	d” 0.4	d” 0.8	0.00003	0.00008	0.015	0.046	0.12
Mn	950	d” 1,000	850	< 0.0001	0.012	630	0.2	860
Mo	1.5	d” 2.5	2	< 0.0001	0.00035	0.9	<0.2	d” 10
Ni	75	d” 70	40	0.0054	0.01	3	0.8	49.7
Pb	12.5	d” 20	10	0.00003	0.005	2.7	2	34.9
Sn	2	d” 6	10	< 0.0001	0.00004	0.3	< 0.15	< 10
V	135	d” 130	100	0.0019	0.001	1.6	0.15	d” 150
Zn	70	d” 100	50	< 0.0001	0.01	100	160	110.6

lization processes (Gibbs 1970). River sediments can be described as the product or residue of weathering (Singh et al. 2005). River Sadong consists mainly of clays and silts with moderate to abundant plant remains (Lam 1988). Chemical weathering of rocks and soils in this area occurred during the physical erosion of source rocks, movement of sediments in fluvial systems and sediment recycling (Nesbitt & Young 1996). The mineralogical and chemical compositions of sediments provide important information about their sources and this can be useful in inferring paleoclimate changes, weathering trends, sediment characteristics, provenance of the sediment, chemical speciation of their constituents and the depositional environment (Wei et al. 2006, Naimo et al. 2005, Glasby et al. 2004, Calvert et al. 2001, Nesbitt & Young 1996). The chemical load of Sadong River water is from diverse sources (Huy et al. 1998) and their mobility is controlled by the larger amounts of fine particles of both silt and clay. The organic matter is bound with heavy metals to form stable complexes. Carbonates and silicate constituents are usually in high proportion in river sediments, this has contributed to the high alkalinity and buffering of sediments. This makes it necessary to use acids to extract the heavy metals from these sediments.

THE TOXICITY OF HEAVY METALS

Heavy metals are believed to be toxic and carcinogenic to living organisms (Clement et al. 1995, MacCarthy et al. 1991). Their non-biodegradable nature and toxicity is of a great concern in the aquatic system (Nair & Sujatha 2013). They tend to be stable in the river for over a long period of time, this cause concerns arising from their ubiquity in this environment. At elevated levels, heavy metals are known to threaten human lives and deteriorate the river (Table 5). The contamination maxima of heavy metals tend to be localized rather than widespread (Andrews 2004). The concentration of detritus constituents is reflected in the major oxide geochemistry, while the trace element studies indicate ferruginous nature of some elements (Sundararajan & Srinivasalu 2010). They possess significant environmental threat because of their wide variety of sources, non-biodegradable characteristics and accumulative behaviour (Monisha et al. 2014).

THE ENVIRONMENTAL POLLUTION INDEX

The natural flux of heavy metals from the catchment areas and anthropogenic sources are the main origin of geochemical elements and the extent of complexation as well as the oxidation state are the factors which determine the form of the heavy metal ion. However, the assessment of the impact of heavy metal pollution on river sediments can be determined by using different reference materials and enrichment calculation methods (Forstner & Salomons 1980, Hakanson 1980, Muller 1969).

One of the most common methods to differentiate the amount of heavy metals or enrichment is by the normalization with respect to aluminium (Al) (VanMetre & Callender 1997, Loring 1978, Kemp et al. 1976). The most widely used normalizer is aluminium (Al) because it compensates for variations in the grain size and composition as well as represents the quality of alumino-silicates which is the most important carrier for adsorbed metals in the aquatic environments. The normalized concentration is varied and is expressed as enrichment factor (EF), this is the ratio of the content of the element in the analysed layer to the content

Table 5: Sources and effects of some heavy metals found in natural water.

Metal	Sources	Effects
Arsenic (As)	Natural: Weathering and volcanism Anthropogenic-Mining, chemical waste	Toxic and carcinogenic to human and animals
Cobalt (Co)	Natural: rocks, soil and plants Anthropogenic: combustion of fuel, Mining, industrial waste	Toxic to plants and algae at high levels
Copper (Cu)	Natural: dark leafy plants, shell fish Anthropogenic: Metal plating, electrical manufacturing, agro-chemicals, Mining, industrial waste	Toxic to plants and algae at high levels
Iron (Fe)	Natural: rocks, soils, leguminous plants Anthropogenic: Mining, Steel production, Fuels, industrial waste	Damage fixtures by staining, corrosion of water pipes
Lead (Pb)	Natural: Earth crust Anthropogenic: Metal plating, Mining, combustion of fuel, paints, batteries, industrial waste	Harmful to human and wildlife
Manganese (Mn)	Natural: microbial action Anthropogenic: Metal plating, Mining, industrial waste	Toxic to plants
Nickel (Ni)	Natural: Weathering, vegetation, wind-blown dust Anthropogenic: Metal plating, Mining, combustion of fuel, industrial waste	Toxic to plants and algae at high levels
Zinc (Zn)	Natural: Earth crust Anthropogenic: Metal extraction and production, Mining, industrial waste	Toxic to plants at high level

corresponding to the undisturbed (pre-industrial) period. It is a useful tool for the determination of the anthropogenic heavy metal pollution. The EF is computed using the relationship below:

$$EF = \frac{(Metal/Al)_{sample}}{(Metal/Al)_{Background}} \quad ...(1)$$

Where, an EF around 1.0 indicates that the sediments originated predominantly from lithogenous material, whereas an EF>1 indicates that the heavy metal is of anthropogenic origin (Szefer et al. 1996). Aluminium is widely used as a reference element because it is found in most rocks and associated with fine solid surfaces. The geochemistry of aluminium is similar to that of many trace metals and its natural concentration tends to be uniform. Generally, EF<1 indicates no enrichment, EF<3 indicates minor enrichment, EF<5 indicates moderate enrichment, EF<10 indicates moderately severe enrichment, EF<25 indicates severe enrichment, EF<50 indicates severe enrichment and EF>extremely severe enrichment.

Generally, the determination of the degree of pollution by a given heavy metal requires that the concentration of the heavy metal of interest (pollutant) be compared with an unpolluted substance that is comparable with the studied samples (Maanan et al. 2015). The geoaccumulation index (I_{geo}), is determined to ascertain the extent of pollution in sediments (Hahladakis et al. 2013). A common method to estimate the enrichment of metal concentrations above background or baseline concentration is to calculate the I_{geo} as proposed by Muller 1969 (Table 6).

HYDROCARBON BIOMARKERS AS TOOL IN RIVER SEDIMENT ANALYSIS

Sediments are the final sinks of hydrocarbon because they bind rapidly to particulate materials in aquatic environments. The two classes of hydrocarbons found in the fluvial environment are aliphatic hydrocarbon and polycyclic aromatic hydrocarbons (Tahir et al. 2015, Sakari et al. 2008, Zakaria et al. 2002). The naturally derived hydrocarbons are controlled by different metabolic pathways or biosynthetic processes that results in the formation of other complex biological structures in the environment. Forests are important sources of organic compounds such as terpenes, organic acids and aldehydes. Sadong basin environs have damp soils especially peat as well as marshes or rice paddies are microbiologically dominated environments which serves as food for man and animals (Andrews et al. 2004). While anthropogenic hydrocarbons are derived from human activities such as industrialization, mechanized agricultural activities and urbanization. The chemical composition of petroleum product is very complex and it changes over time

Table 6: Geoaccumulation index of Heavy Metal concentration in sediments (Muller 1969).

Geoaccumulation Index	Class	Pollution Intensity
0	0	Background concentration
0-1	1	Unpolluted
1-2	2	Moderate to unpolluted
2-3	3	Moderately polluted
3-4	4	Moderately to highly polluted
4-5	5	Highly polluted
>5	6	Very highly polluted

when it is being released into the environment.

HYDROCARBON BIOMARKER INDICES

Generally, the biogenic derived hydrocarbons appear with low concentrations in river sediments while those of high level of hydrocarbon compounds are believed to have an anthropogenic source which often cause petroleum pollution. Some indices were used to identify the sources of hydrocarbon in previous studies such as Carbon Preference Index (CPI), Low Molecular Weight to High Molecular Weight ratio (LMW/HMW), Average Carbon Chain and the Unresolved Complex Mixture (UCM) (Zakaria et al. 2002).

CONCLUSION

This review gives an understanding of the sedimentological and geomorphological characteristics of River Sadong, which is useful in the environmental assessment of the river. Sediments are very significant because they are carriers of trace metals in the hydrological cycle.

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