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Spatial and Temporal Variation of Organic Carbon in Mangrove Sediment of Rembau-Linggi Estuary, Malaysia

[1]Muhammad Raza, [1]Mohamad Pauzi Zakaria and [2]Nor Rasidah Hashim

[1]Center of Excellence for Environmental Forensics, Faculty of Environmental Studies,
Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia
[2]Department of Environmental Science, Faculty of Environmental Studies,
Universiti Putra Malaysia, 43400, UPM Serdang, Selangor, Malaysia

Abstract: Mangrove sediments act as site of organic carbon accumulation in estuary. This paper aims to determine the distribution of OC content in mangrove sediment in mangrove root zone. Three replicate samples of mangrove sediment were collected from seven stations. Six *in-situ* water quality parameters were measured during low tide along the river. The OC content in mangrove sediment varied significantly among sampling stations with values ranging from 13.6 to 26.0 mg/g. OC content in five stations namely station 1, 2, 3, 5 and 6 noted to have increased significantly from 6.56 % to 26.42 % after six months interval. There were no significant correlations between OC content in mangrove sediment with the six in-situ water quality parameters measured. The variability in OC content in each station indicates that anthropogenic activities and land uses in the area have influence on the distribution of OC content in this estuary.

Key words: Organic carbon · Mangrove sediment · Anthropogenic activities · Water quality · Land use

INTRODUCTION

Mangrove forests are among the most productive ecosystem in the world. Malaysia is covering 11.7 % of total mangrove areas in Southeast Asia with 42 mangrove plant species recorded in its vicinity [1]. As the mangrove forests are generally found along coastal areas and river estuaries, they are more prone and easily exposed to anthropogenic activities and contamination from sea-based and land-based sources. Mangrove ecosystem is described by the abundance of detritus litters such as leaves in the area. With high sedimentation rate and conditions of reduced current flow in these areas, the mangroves provide a special ecosystem for organic carbon (OC) to sink and sequestered in the sediment. The estuarine and mangrove sediments are dynamic matrixes which receives OC inputs derived from both terrestrial and aquatic origins. Moreover, OC derived from domestic, agricultural and industrial wastes could significantly contribute to the global carbon budget. However, they are difficult to quantify [2, 3].

This paper had focused on the OC distribution in Rembau-Linggi estuary and aimed to find out the correlation between the OC distribution pattern with river water quality, anthropogenic activities and land uses that occurs within the estuary. The Rembau-Linggi estuary is a riverine mangrove forest located in West Coast of Peninsular Malaysia which facing the Straits of Malacca. This estuary consists of Rembau River and Linggi River; where Linggi River is the main water source that provides raw water for Port Dickson District and the surrounding area. Land uses within four kilometers around the estuary are palm oil plantations, charcoal factory, chicken farming, Kuala Linggi port, aquacultures as well as human settlement. Mangrove forest along the estuary consists of *Sonneratia spp. Rhizophora spp. Avicennia spp.* and *Nypa frutican*; which functionally and geomorphologically can be categorized as mangrove riverine forest. There are many kind of aquatic organisms in Rembau-Linggi estuary such as estuarine crocodile (*Crocodylus porosus*) [4], goby fish (*Microgobius gulosus*), giant river prawn

Corresponding Author: Mohamad Pauzi Zakaria, Center of Excellence for Environmental Forensics,
Faculty of Environmental Studies, Universiti Putra Malaysia,
43400, UPM Serdang, Selangor, Malaysia.
Tel: +603-89468024.

(*macrobrachium rosenbergii*), eel-tail catfish (*plotosus sp*.), climbing perch fish (*Anabias testudineus*) and others. Objectives of this paper are: 1) to determine spatial variation of organic carbon in Rembau-Linggi estuary; 2) to determine temporal variation of OC in Rembau-Linggi estuary between two different months; 3) to determine the correlation between OC content and water quality in study area.

MATERIALA AND METHODS

Sample Collection: Three replicate samples of mangrove sediment were collected from seven stations in Rembau-Linggi estuary, Negeri Sembilan, Malaysia (2.6° N; 102.0° E) in two different months namely on 29 January 2009 and 10 August 2009 (Figure 1). The time interval between these two sampling months is six months (182 days). Stations 1 - 3 are located within Rembau River whereas stations 4 - 7 are located within Linggi River (Table 1). The samples were taken only from the area with *Sonneratia spp.* with pneumatophore in order to avoid environmental variation. The surficial mangrove sediment (0-5 cm) were collected using Eijkelkamp hand auger and placed on a stainless steel pan; then transported to the laboratory using cooler box with ice. The samples were stored at 4°C in an ice box until further analysis. All the materials in contact with the samples were previously washed with distilled water, methanol, acetone and hexane in sequence. Six in-situ water quality parameters namely dissolve oxygen (DO), salinity, temperature, electrical conductivity (EC), pH and turbidity were also measured during low tide at the seven stations along the river in order to determine the general characteristic of the Rembau-Linggi estuary river water.

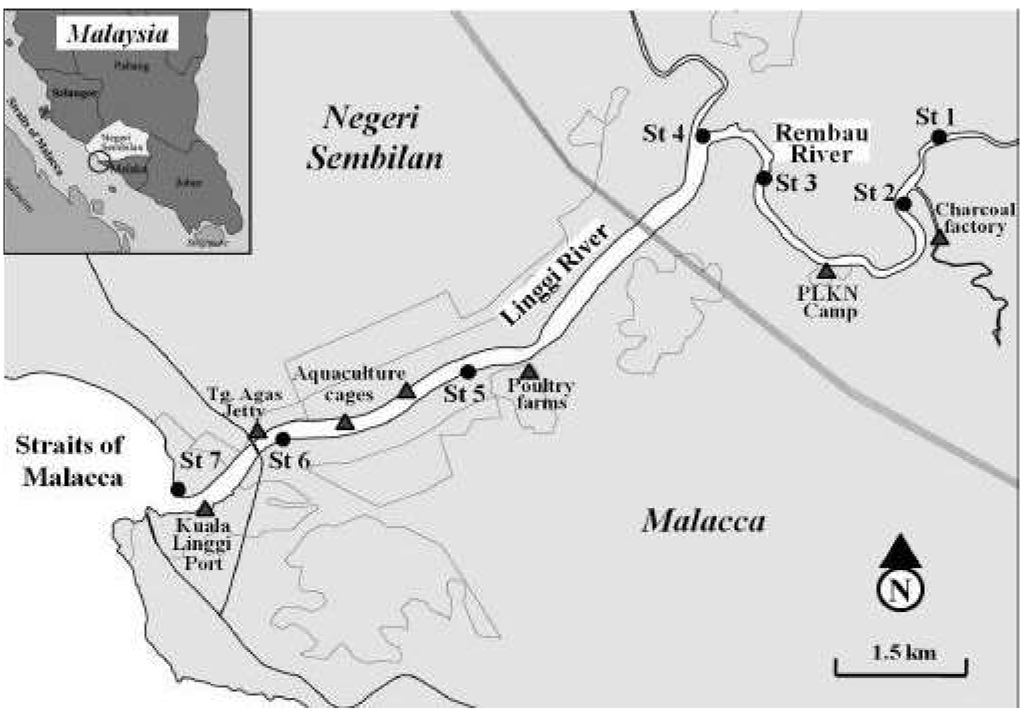

Fig. 1: Sampling stations in Rembau-Linggi estuary, Negeri Sembilan, Malaysia

Table 1: Types of mangrove plants exist at seven sampling stations

Station	River	Mangrove plants
1	Rembau river	*Sonneratia spp. and Nypa frutican*
2	Rembau river	
3	Rembau river	
4	Confluence of Rembau and Linggi river	*Sonneratia spp. Avicenna spp. and Nypa frutican*
5	Linggi river	*Sonneratia spp. Avicenna spp. Nypa frutican and Rhizophora spp.*
6	Linggi river	
7	Linggi river	

Organic Carbon Analysis: The sediment samples were dried overnight at 60°C in oven and ground thoroughly to a fine powder using mortar and pestle. Then the samples were passed through a 2 mm mesh sieve in order to get homogenous samples [5]. Sediment, plant roots and detritus retained in the sieve were discarded to avoid additional contribution of OC content in the sieved samples. Acidification procedure was used in order to eliminate inorganic carbon (carbonates) that contained in the samples. 1-2 g of each sample was weighed and 1-2 ml of 1M HCL was added drop by drop until the sample is completely moist with HCL. The samples were dried at 100°C for ten hours to remove hydrochloric acid. 1 g of each sample was reweighed and then analyzed using LECO CR-412 Carbon Analyzer at 1350°C for 60s to determine the total organic carbon (TOC) percentage [6].

Statistical Analysis: Several statistical tools were applied in this study in order to determine the homogeneity of variances, normality and differences between sampling stations. The mean and standard deviation values of three replicate samples in each station were calculated. The data were checked for homogeneity of variances by Levene's test and normality by Kolmogorov-Smirnov test. The differences in OC content between stations were determined by analysis of variance (ANOVA). Differences were considered significant only when p values were lower than 0.05. Once the significant differences were detected, the least significant differences (LSD) test were performed. Spearman rho correlation coefficient (r) was done to determine the relationship between the OC and in-situ water quality parameters.

RESULTS AND DISCUSSION

Spatial Variation of Organic Carbon: The organic carbon (OC) content in mangrove sediment varied significantly (p = 0.04) among the sampling stations (Table 2). The values ranged from 13.6 to 26.0 mg/g (mean of two months). Station 6 significantly shows the highest amount of OC content compared to the other stations which are located downstream of Linggi River. From direct visual observation conducted during sampling session, we found that there were aquacultures cages of fish cultivation and a bridge, namely the Kuala Linggi Bridge which are located about 400m and 300m from Station 6 respectively (Figure 1). Spatial distribution of OC in Rembau-Linggi estuary is generally influenced by the different land use type that exist in the area such as mangrove forest, aquaculture, oil palm plantation, forest, coconut plantation, cleared land, poultry farm, rubber, secondary forest and residential area. There are also human-based activities occurring in the estuary for instance charcoal transportation at Kuala Linggi port, fishing, charcoal production factory and mangrove forest deforestation. Charcoal has a significant influence on the dynamics of sediment organic carbon which under exploitive cultivation, soil with high in charcoal content appears to resist organic carbon decline [7]. Different land use patterns and changes in the mangrove estuary have resulted in the varied content of OC in sediment [8-10]. This is consistent with this study where land use types of Rembau-Linggi estuary do affect and influence the distribution of OC content in sediment in each station.

The types of mangrove plants that exist along the study area were identified by direct observation method during sampling session (Table 1). The distribution of mangrove plants in this estuary is primarily determined by sea level and geomorphology of the estuary. The abundance mangrove plant existing is *Nypa frutican* where they live in large quantity in all stations. Conversely, *Rhizophora* is the rare species where only can be found to live at station 5, 6 and 7. Station 6 is mostly dominated by *Rhizophora* and *Sonneratia* species which have stilt root and pneumatophore root respectively. These roots have capability to trap detritus, suspended sediment particles as well as litter and accumulate them in the mangrove root zone. This process is able to provide an influence to OC contribution in the nearby mangrove sediment. Furukawa *et al.* [11] found that 80% of the suspended sediment brought in to the mangroves from coastal waters was trapped in the mangroves whereby the particles were being trapped in the stagnation zones around the mangrove root area.

The lowest OC content was recorded in Station 4 which is located at the confluence of the Linggi River and Rembau River. This area is dominated by mudflat where the mangrove plant does not exist. Therefore the mudflat were not affected or influenced by the mangrove roots and leaves which would be the contributor and the main source of organic matter to the sediment. Mangrove ecosystems are able to accumulate large amounts of organic carbon [12-14]. Moreover, organic-rich sediment has been found in several meters depth in some mangrove ecosystems [15, 16]. As a comparison, Kamaruzzaman *et al.* [16] found that OC content in bottom sediment of Pahang river estuary were at an average of 0.88 mg/g and varied from 0.9 to 20.5 mg/g, much lower compared to this study which the OC content was found to be at the average of 18.6 mg/g and varied from 13.6 to 26.0 mg/g.

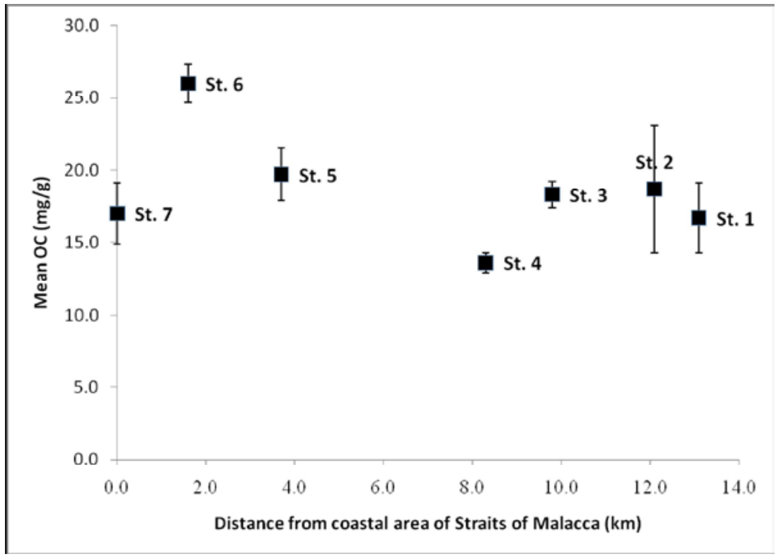

Fig. 2: Distance of the sampling stations from coastal area of Straits of Malacca and OC content

In order to understand the influence of tidal gradient to the OC content in the sediment, the distance between sampling stations and coastal area of Straits of Malacca were measured [5]. We found that the OC content in each station showed variability but they were not totally influenced by the distance of the sampling stations from coastal area of Straits of Malacca (Figure 2). In contrast, Zhang *et al.* [18] found that sediment OC content was clearly higher in the estuary than in the coastal area and showed a decreasing trend with the increasing distance from the river mouths. Zhang *et al.* [18] suggested that the sampling location near the river outlets was impacted by the river terrestrial organic matter. Additionally, Tam and Wong [5] found that the sediment OC content were high in landward sites and decreased gradually towards the sea with an average content of 8.78 and 5.46%. Tam and Wong [5] concluded that the low organic matter content in area near the sea was probably due to frequent tidal flushing which rapidly exports mangrove litter.

Temporal Variation of Organic Carbon: Temporal distribution of OC content in mangrove sediment for two times sampling at seven stations was shown at Table 2. The first sampling trip was conducted on 29 January 2009; and on 10 August 2009 for the second sampling trip. The time interval between these two sampling trips is six months, in which the month of January experienced rainy season of the Northeast Monsoon [19-22] and in August, the dry season of the Southeast Monsoon [19, 20, 23]. The Southwest Monsoon usually begins in the latter half of May or early June and ends in September where Negeri Sembilan will experience dry season in June, July and August [23]. The Northeast Monsoon usually begins in early November and ends in March, where most districts in Peninsular Malaysia will experience rainy season [23].

From the results, we found that the maximum and minimum concentration of sediment OC for both January and August were recorded at the same stations which are Station 6 and Station 4 respectively. After six months interval, OC content in five stations which are Station 1, 2, 3, 5 and 6 had significantly increased from about 6.56 % to 26.42 %. In contrast, Station 4 and 7 recorded a significant decrease of OC content at 4.19 % and 4.41 % respectively. The sediment OC content has significantly changed from January 2009 to August 2009 at 0.05 confidence level (Table 3). However, Alongi *et al.* [24] found that the OC content in mangrove sediment from four mangrove forests of southern Thailand were not significantly different between Southwest Monsoon season and Northeast Monsoon season, where the mean values of OC content ranged from 23.4 to 73.5 mg/g in both seasons.

Correlation of Organic Carbon and River Water Quality: Six in-situ water quality parameters were taken from station 1 until station 8 along the mangrove estuary during the low tide. Salinity and EC were statistically significant positive correlated between each other's where

Table 2: OC content in mangrove sediment at seven sampling stations (mg/g)

Station	OC (January 09)	OC (August 09)	Mean of two months
1	15.0 ± 2.7	18.4 ± 2.1	16.7 ± 2.4
2	16.2 ± 5.1	21.2 ± 3.8	18.7 ± 4.4
3	17.7 ± 1.1	18.9 ± 0.7	18.3 ± 0.9
4	13.9 ± 0.4	13.3 ± 0.9	13.6 ± 0.7
5	17.6 ± 1.4	21.8 ± 2.1	19.7 ± 1.8
6	24.7 ± 1.9	27.3 ± 0.7	26.0 ± 1.3
7	17.4 ± 2.5	16.7 ± 1.7	17.0 ± 2.1
Max	24.7	27.3	26.0
Min	13.9	13.3	13.6
Median	17.4	18.87	18.3
Mean	17.5	19.7	18.6

Table 3: The changes of OC content for six months interval

OC Content	Mean	SD	*t*	*p**
January 09	19.7	4.41	2.52	0.225
August 09	17.5	3.48		

*Reject the null hypothesis

*The OC content was significantly change from January 09 to August 09 at 0.05 level of significance

Table 4: Spearman rho correlation coefficient (*r*) between OC content and six in-situ water quality parameters in Rembau-Linggi estuary

	DO	Salinity	Temperature	EC	pH	Turbidity	OC
DO	1.00	-0.393	0.667	-0.5	-0.222	0.429	-0.036
Salinity		1.00	0.234	0.964**	0.593	-0.964**	0.571
Temperature			1.00	0.018	0.449	-0.27	0.234
EC				1.00	0.408	-0.893**	0.536
pH					1.00	-0.704*	0.296
Turbidity						1.00	-0.393
OC							1.00

the values of these two parameters increase downward towards the downstream of the Linggi River. However, in terms of correlation with OC, all of the six in-situ water quality parameters were found to be not significantly correlated with OC content (Table 4), which means that these parameters did not affect OC content and distribution in the mangrove sediment.

Although OC content and water quality parameters were found to be not significantly correlated, both of them play major function in the distribution of organic pollutants in mangrove sediment. Freshwater entering the ecosystem as well as wastewater discharges from nearby area have contribution in organic matter content in mangrove ecosystems. Ovalle *et al.* [25] found that freshwater input as well as other terrestrial-derived carbon and nutrients to the mangrove forests are mainly caused by runoff. Moreover, Jagtap [26] reveal that terrestrial runoff contributed high levels of particulate and organic matter to the mangrove ecosystem mainly during monsoon months. The landward edge of mangrove ecosystem which often used as dumping sites for wastes and wastewater could bring in organic matter [27].

Wastes from various anthropogenic activities for instance domestic refuse, litter, building and construction wastes were commonly found at the back of the present mangrove ecosystem [5]. The anthropogenic activities in the estuary such as aquaculture (fish farming) effluents, domestic effluent from the villages nearby, palm oil plantation as well as the deforestation of the mangrove forest [28] were believed to have contribution to the pattern of the OC content and river water quality. Excretion of fish waste products, death and decomposition from fish farming and effluents could contribute to the OC content in river water, eventually will influence the OC content in nearby mangrove sediments. Natural processes and anthropogenic activities such as forest clear cuttings, agricultural practices and changes in land uses have resulted in elevated content of OC in soil, sediment and streams [28]. Abril *et al.* [8] found that human activity such as wastewater loads has significantly contributes to the organic carbon in European rivers and estuaries, which this might also be the case in other continents especially in developing countries where sewage treatments are inefficient.

CONCLUSION

From the analysis of results, we concluded that there was no significant correlation between TOC content in mangrove sediment with the six in-situ water quality parameters measured in the area. Station 6 which is located 10km from the coastal area of Straits of Malacca significantly shows the highest amount of OC content while the lowest OC content was recorded at Station 4 which is located at the confluence of Rembau River and Linggi River. The variability in OC content in each station indicates that anthropogenic activities and land uses in the area have influence on the distribution of OC content in the estuary. Anthropogenic activities in the estuary such as aquaculture (fish farming) effluents, domestic effluent from the villages nearby, palm oil plantation as well as the deforestation of the mangrove forest were believed to be the probable contributor to the pattern of the OC content and river water quality. However, it is difficult to point out which sources have significant contribution to the OC content in mangrove sediment. This is because OC content in mangrove sediment were regulated by various biogeochemical factors including inputs from surface runoff, human activities and disturbance, tidal water flushing from Straits of Malacca, detritus, litter accumulation and decomposition as well as plant species distribution. This study demonstrates the importance of mangrove estuarine sediments playing role as site of organic carbon deposition and accumulation in Malaysian mangrove ecosystem.

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