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ESTIMATION OF SEDIMENT ACCUMULATION RATE AT DIFFERENT SEASON IN JURU RIVER AND PERAI RIVER (PERAI INDUSTRIAL AREA, PENANG, MALAYSIA)

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ABSTRACT

Two sediments cores were collected from each Juru River and Perai River at the Penang's Perai Industrial Area during two different seasons and analyzed using nuclear techniques, with the purpose to evaluate the sediment accumulation rates at the study area. Radioactivities of ^{137}Cs, ^{210}Pb and ^{226}Ra activity profiles were determined for each core by using gamma spectrometry system. However, due to the complexity of the excess ^{210}Pb activity profiles obtained, it was not possible to obtain an age model from them. Nonetheless, preliminary apparent sediment accumulation rates were estimated, and were found to range between 0.94 – 4.91 cm/y and 1.79 – 4.83 cm/y for Juru and Perai River, respectively. As expected, the deposition rates were higher during rainy period where the value at Juru River almost five folds, and at Perai River, it was 2.5 times higher than that of the dry season. The highest sedimentation rate recorded was in the core collected at the Juru River (SP 03) during the rainy season.

Keywords: Juru River, Perai River, radionuclides, sediment accumulation rates, season

INTRODUCTION

Nearly 40% of the world's population live within 100 km of the coastal areas, where people derive benefit from the use of coastal and marine resources and create employment linked with coastal and maritime activities, as well as from the coastal recreational opportunities (Raven, 2001; United Nation, 2017). Development of the coastal zone, exploitation of its natural resources, and its use as a receptacle for societal wastes promote sediment contamination and endanger the living marine resources (Cochran and Masque, 2004).

Sediment is a combination of complex materials contributed by rivers, coastal erosion, biological and chemical processes, as well as anthropogenic waste. Weathering is one of the major sources of sediments; however, the rapid economic growth and settlement development can drive the release of waste materials into the coastal area and accumulate into the sediment (Joseph et al., 2018). Natural radionuclides in the sediment such as ^{210}Pb ($T_{1/2}$ = 22.20±0.22 years) could then be utilized as a powerful tool for the determination of mass fluxes in the marine environment, particularly for investigation of recent sedimentation. The deposition rate of contaminants in sediment can be estimated using the natural radionuclide profiles of ^{210}Pb in a sediment core, where the sedimentation rates can be estimated by employing different mathematical models. Pb-210, a member of the ^{238}U decay series, is present in the sediments through two main routes. First, there is a ^{210}Pb fraction continuously produced *in situ* from ^{226}Ra ($T_{1/2}$ = 1600±7 years); this fraction, known as background or supported ^{210}Pb, is assumed to be in radioactive secular equilibrium with ^{226}Ra. Meanwhile, ^{222}Rn ($T_{1/2}$ = 3.8235±0.0003 days) which is a noble gas, emanates from the Earth's surface and goes into the atmosphere where it decays into ^{210}Pb, which is removed from the atmosphere back by wet precipitation and/or dry fallout to the Earth's surface will contributing as

the unsupported or excess fraction of ^{210}Pb (Krishnaswami et al., 1971). This atmospheric addition of ^{210}Pb is in excess of the amount permanently supplied by the *in situ* decay of ^{226}Ra. As time goes by, the activity of excess ^{210}Pb will decay until it reaches secular equilibrium with the supported ^{210}Pb fraction (^{226}Ra). The activity differences between the initial excess ^{210}Pb (at the surface of the sediment core) and the subjacent core sections can be used to estimate the time of when the sediment at this section was deposited (Aliev et al., 2007; Chakrabarty et al., 2006; Likuku, 2006; Sanchez-Cabeza and Ruiz-Fernández, 2012; Wan Mahmood et al., 2016).

Cs-137 ($T_{1/2}$ = 30.0±0.2 years) is an artificially created radionuclide which was released by a series of atmospheric nuclear tests during the mid-twentieth century. Atmospheric deposition of ^{137}Cs first began in 1954, then with one huge peak fallouts occurred in 1963, with yet another peak taking place in 1986 resulting from the accident at the Chernobyl power plant, and eventually from the accident of Fukushima power plant in 2011. The ^{137}Cs has always been used by scientists in verifying the sedimentation rate estimation model from $^{210}Pb_{ex}$ method. Furthermore, ^{137}Cs concentrations in sediment have also been measured by a number of researchers to estimate the sedimentation rates which have occurred in the past 50 years (Wan Mahmood and Yii, 2013).

Perai Industrial Estate is one of the major industrial parks in Penang state of Malaysia located on the northwest coast of Peninsular Malaysia, by the Malacca Strait. It consists of two parts: the Penang Island, and the Seberang Perai (formerly known as Wellesley Province) on the mainland Malay Peninsula. The Perai Industrial Estate covers an area of about 15 km^2 and is framed by the Perai River to the northwest, Juru River to the east, the Penang Channel to the southwest and Baru Street, Perai to the north (Figure 1). The Perai Industrial Estate was established in the 1970s in response to the need of industrial expansion and with limited land area on the Penang Island, the coastal area of Perai was selected. This was further boosted when the 13.5 km long Penang Bridge was completed in 1985. With improved access to the Penang international airport on the Penang Island, many more companies set up factories in this area. Bulk cargo is also conveniently shipped through the Perai Bulk Cargo Terminal which is situated next to the Perai River. Due to heavy industrial development and associate population growth in the surroundings of Perai industrial area, industrial and household discharges, terrestrial materials were suspected to be released into the nearby rivers; and Juru River is reported as one of the most polluted river in the country (Zainudin, 2010). Run-off terrestrial soils and material turns up to be sediment and accumulated in the aquatic system. Sediments not only bring in contaminants but water polluted with sediment becomes cloudy and the increase in water turbidity will prevent animals from seeing food. Murky water also prevents natural vegetation from growing in water. High sediment in stream beds will disrupts the natural food chain by destroying the habitat where the smallest stream organisms usually live and this in long run will cause massive declines in fish populations.

This study is aimed to estimate the sediment deposition rates in the sediment cores collected during two different seasons from Juru River and Perai River, Penang that might have been promoted by the economic development and population growth in the Perai Industrial area and compared the differences among them.

MATERIALS AND METHODS

Sample Collection and Preparation

Four sediment cores were collected, by using a KC™ Kajak Core Sampler with a 8 cm diameter PVC tube, during the dry and rainy seasons between 2017 and 2018 at the upper river, in Juru River and Perai River (Figure 1 and Table 1). Each core was extruded from the bottom of the tube and sliced into 2 cm thick sections at the sampling site; samples were placed into HDPE plastic bag and refrigerated until further analysis. Back in the laboratory, sediments were weighed and small portions of samples were taken for sediment particle size analysis, re-weighed and dried in an oven at 80°C until constant weight (IAEA, 2003). The dried samples were fine ground using a Rocklabs® grinder mill to obtain homogeneous powders of less than 200 mesh (74 μm) size. All data in this study was reported on a dry weight (dw.) basis.

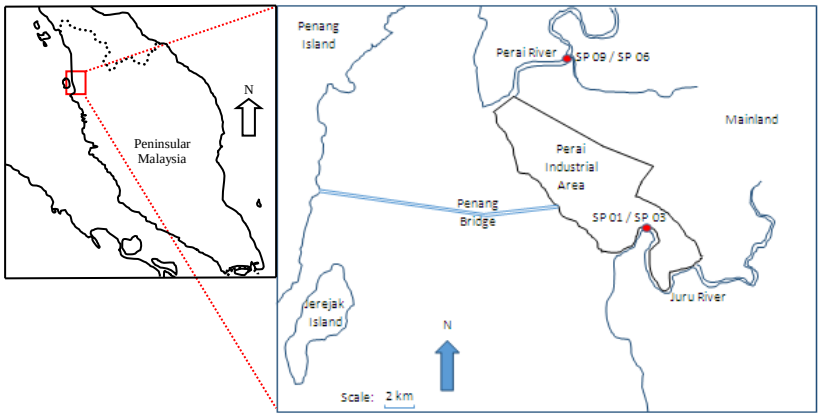

Figure 1: Sampling location

Table 1: Sampling location details

Date	Station	Coordinate	Core length (cm)
Feb 2017 (dry)	SP 01, Juru River	5.3464°N; 100.4189°E	74
Nov 2017 (rainy)	SP 03, Juru River		38
Nov 2017 (rainy)	SP 06, Perai River	5.3992°N; 100.3927°E	56
July 2018 (dry)	SP 09, Perai River		62

Particle Size Analysis

Particle size distribution in the wet sediment sample was analysed with a Microtrac™ X100 laser diffraction in the laboratory. Using the Udden–Wentworth scale, particles were characterized into fraction of sand (> 63 µm), silt (4 – 63 µm) and clay (< 4 µm) (Blair and McPherson, 1999; Blott and Pye, 2012; Krumbein and Aberdeen, 1937).

Loss on Ignition

A rough estimation of organic matter content (% OM) in soil/sediment samples was based on the Loss on Ignition (LOI) analysis. It does not involve the use of any chemicals, but only using a muffle furnace. LOI calculates % OM by comparing the weight of a sample before and after the soil/sediment has been ignited. Organic matter is oxidized to carbon dioxide and ash at temperatures between ~200 and 500 ºC. Weight losses associated with water and carbon dioxide evolutions are easily quantified using equation (1) and (2) below by recording sample weights before and after controlled heating (ignition at 550 and 1000 ºC) and, in turn, may be correlated to water content, and organic matter and carbonate content (Nelson and Sommers, 1982). Using equation (1) and equation (2) below, the percentage of organic carbons and the carbonate were calculated for every section of sediment core.

$$\%\,\text{Organic Matter} = \frac{(Weight\ \ Post\ \ 105^{o}C\ \ Dry\ \ sample) - (Weight\ \ Post\ \ 550^{o}C\ \ Ash)}{(Weight\ \ Post\ \ 105^{o}C\ \ Dry\ \ sample)} \times 100 \quad \text{eq (1)}$$

$$\%\,CaCO_3 = \frac{(Weight\ \ Post\ \ 550^{o}C\ \ Ash) - (Weight\ \ Post\ \ 1000^{o}C\ \ Ash)}{(Weight\ \ Post\ \ 105^{o}C\ \ Dry\ \ sample)} \times 2.274 \times 100 \quad \text{eq (2)}$$

where 2.274 = 100.088 / 44.009 = molecular weight $CaCO_3$ / molecular weight of CO_2.

Radionuclides Analysis

Fine ground dry sediments from each section of the core were put in a 6 ml cylindrical HDPE container and sealed using thick PVC tape to inhibit radon from escaping (Yii et al., 2016). Net weight of each sample was recorded and divided by the sample volume to get the sample density. All samples were stored for a minimum period of 30 days to establish secular equilibrium between ^{226}Ra and their respective progenies prior to gamma counting (Dowdall and O'Dea, 2002; Yang et al., 2005). Radionuclides activities of ^{137}Cs, ^{210}Pb and ^{226}Ra were determined by using CANBERRA™ gamma-ray spectrometry consisting of a high-purity germanium (HPGe) setup and a 16,384 channels multichannel analyser. The detector used is a closed end coaxial well-detector that operated at 2,000 HV bias supply (detector: 62 mm diameter, 49 mm, and 5 mm distance from the window; well: 35.5 mm depth, 23.5 mm diameter, active volume of 8.8 cc). This p-type detector with the FWHM resolution of 820 eV at 122 keV gamma-ray line of ^{57}Co and 1.85 keV at 1332 keV gamma-ray line of ^{60}Co is designed to provide 25% relative efficiency. The detector is shielded in a 11 cm thick chamber made of lead, cadmium and copper to reduce background radiation. It was calibrated using procedures as reported earlier by Yii et al. (2009) with a customized gamma multinuclide standard source (source no. 1290-84 and 1755-30 from Isotope Products Laboratories, USA) comprising of ^{210}Pb, ^{241}Am, ^{109}Cd, ^{57}Co, ^{123m}Te, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{88}Y and ^{60}Co prepared in the same counting geometry.

All samples were counted for 54,000 seconds and corrected for density and sampling date. Background counts of the gamma system were determined using a container of the same geometry filled with inert material that counted during the weekend. Counting times were long enough to ensure a 2σ counting error of less than 10%. (Ahmed and El-Arabi, 2005; Arogunjo et al., 2005; El-Reefy et al., 2006). The ^{210}Pb was measured directly *via* energy 46.5 keV peak and ^{137}Cs was measured directly *via* energy 661.62 keV peak. Meanwhile, ^{226}Ra (mainly alpha emitter) was measured through the gamma transitions of its progenies; ^{214}Pb (295.21 and 351.92 keV) and ^{214}Bi (609.31 keV, 1120.29 keV and 1764.49 keV) (El-Reefy et al., 2006; Mishra and Sadasivan, 1971; Yang et al., 2005). The sample activities were calculated using equation from Yang et al. (2005) and Chen et al. (2005). The minimum detectable activity (MDA) for the radionuclide of interest was: ^{210}Pb (5 Bq/kg), ^{137}Cs (1 Bq/kg) and ^{226}Ra (1 Bq/kg). IAEA's reference materials IAEA-Soil-6 and IAEA-412 were used for quality control evaluation and counted prior of samples counting. The results of samples were accepted if values obtained for the reference material were within the 95% confidence interval (IAEA-Soil-6, ^{137}Cs: 51.43 – 57.90 Bq/kg, ^{226}Ra: 69.56 – 93.42 Bq/kg; IAEA-412, ^{210}Pb: 96.5 – 105.3 Bq/kg, ^{137}Cs: 6.22 – 6.78 Bq/kg, ^{226}Ra: 24.8 – 30.0 Bq/kg) as mentioned in the certificate.

RESULTS AND DISCUSSION

Particle Size Analysis

The sediments in all cores were mostly composed of fine-grained particles (Figure 2). In most core sections, the percentage of silt was higher than the clay, and the clay was higher than that of sand. Overall, for all the cores, the silt contents around 40 – 85%, the clay contents between 10 – 60% , whilst the sand contents around 0 – 40%. Generally, clay contents showed decreasing pattern from the top towards the bottom of the core of SP 09 and also from the 20 cm onwards for core SP 01, but showed an increasing pattern in core of SP 03. These could be due to the re-suspension of the fine particle when the river water flows through the area.

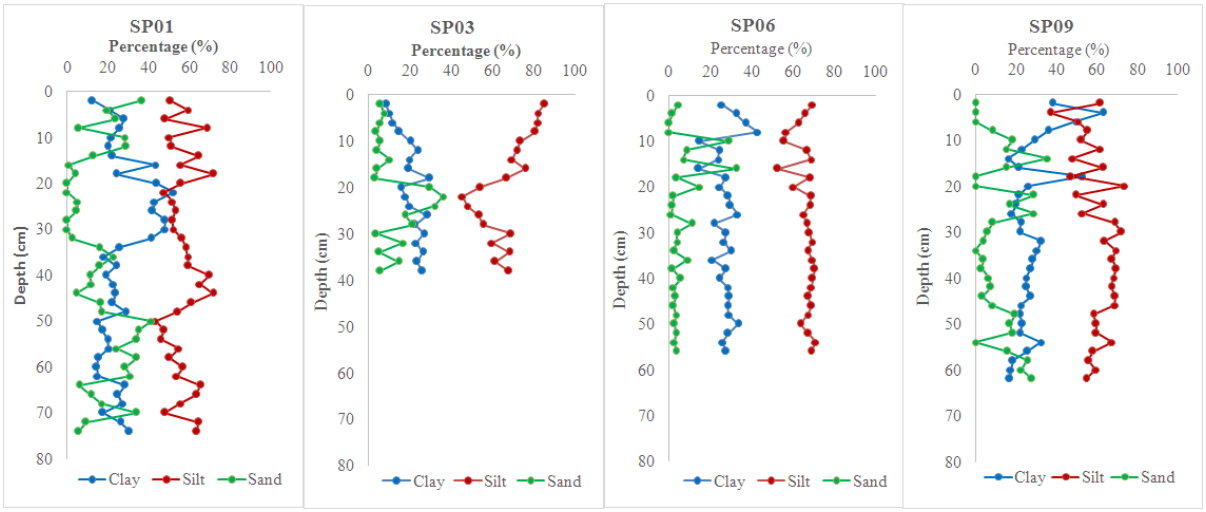

Figure 2: Particle size distribution in sediment cores at study area

Meanwhile, the silt content showed a slight increase from the upper section of the core towards the bottom for core SP 01 and SP 09 whilst the cores of SP 03 had higher contents of silt at the upper part of the core and decreasing towards the bottom which could also due to re-suspension of particles by water flow. On the other hand, the sand contents were low at the top sections of the core SP 03 and SP 09 whilst increasing values were observed at the top portions of core SP 01. Movement of sand might be related to erosion due to nearby river activities and also the volume and speed of water flow in the river. Uniquely, the clay and silt contents in core SP 06 were almost constant from top to the bottom which might due to mixing of the core due to massive water flow and turbulence.

Loss on Ignition

Typically, sedimentary organic matter contains between 40% and 60% organic carbon. The difference in weight between the 550ºC and 1000ºC ashes may (to first approximation) be assumed to result from loss of carbon dioxide during carbonate mineral break-down. However, loss on ignition techniques cannot indicate which carbonate minerals may be present within any given sample. Because calcium carbonate is (typically) the dominant form of carbonate in most lake sediments, weight losses at 1000ºC may nonetheless be used to estimate calcium carbonate content. It should be noted that clay minerals may contain significant quantities of lattice-bound hydroxide (as much as five percent by weight) and these ions may be liberated (as water) at high temperatures. Calcium carbonate content estimates from weight losses at 1000ºC may therefore contain errors as great as five percent and (as such) data results are most appropriately reported as losses by weight percent (Weight % LOI, 1000 °C) (Nelson and Sommers, 1982).

Overall, percentages of organic carbon decreased gradually from the surface sediment towards the bottom of the core whilst carbonate contents were almost constant in all cores (Figure 3). The organic carbon contents in the sediment core of SP 01, SP 03, SP 06 and SP 09 at the study site were between 7.7 – 17.8 %, 6.1 – 16.2%, 8.1 – 10.6%, 6.1 – 19.9%, respectively. The organic contents for the cores in this study were comparable with the finding reported by Wan Mahmood et al. (2016) of between 4.1 – 13.6 %. Significant correlations ($p < 0.05$) were observed between the organic matter and the clay content (Table 2) in sediment cores collected during the dry seasons (SP 01, $r = 0.56$ and SP 09, $r = 0.71$), whilst cores collected during the rainy seasons (SP 03, $r = 0.30$ and SP 06, $r = 0.28$) shows no significant correlation. Water volume and weathering could be the factors behind these differences.

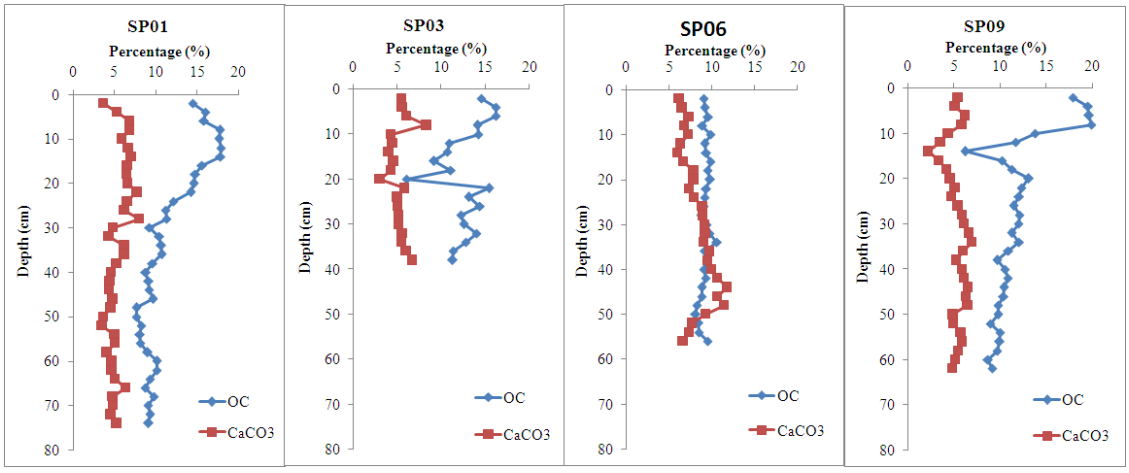

Figure 3: Loss on Ignition in sediment cores at study area

Table 2. Correlation analysis of organic matter with particle size fractions at study site

Station	Correlation Coefficient (r)		
	Clay (%)	**Silt (%)**	**Sand (%)**
SP 01	**0.56**	0.03	-0.15
SP 03	-0.30	0.23	-0.08
SP 06	-0.28	-0.23	0.34
SP 09	**0.72**	-0.30	-0.48

Note: r values in Bold are significant at 95%, "-"value indicate negative correlation

Radionuclide Activities

The activity concentrations for ^{137}Cs, ^{210}Pb and ^{226}Ra in each core were summarized in Table 3 and illustrated in Figure 4. The ^{137}Cs activities were found to be below the detection limit of 1 Bq/kg for all sediment cores and therefore it cannot provide useful information in this study. Meanwhile, ^{226}Ra activities ranges (Bq/kg) were highly variable among cores, with highest values observed in the cores collected at Juru River (Table 3). A single factor ANOVA analysis revealed that ^{226}Ra activities were significantly different between cores from Juru River: SP 01 (97.0±32.8 Bq/kg) ≠ SP 03 (90.2±60.8 Bq/kg) and Perai River: SP 06 (45.7±8.9 Bq/kg) ≠ SP 09 (57.5±26.1 Bq/kg). These values were higher than those found in sediment cores from previous studies in the Asia region (e.g. the Economic Exclusive Zone of the east coast of Peninsular Malaysia, 16 – 46 Bq/kg (Wan Mahmood and Yii, 2012), east coastal area of Peninsular Malaysia, 46.2 – 121.5 Bq/kg (Wan Mahmood et al., 2005) and Vietnam coast, 23.1 – 40.2 Bq/kg (Nguyen et al., 2009)), or elsewhere (e.g. Gulf of Mexico, 11.8 – 97.3 Bq/kg (James et al., 1998); Coatzacoalcos River estuary, Mexico (15.57±1.4 Bq/kg (Ruiz-Fernández et al., 2012); Santos-Cubatão drainage basin, Brazil (28.2 – 80.0 Bq/kg; Sanders et al., 2010), but were much lower than values reported at Krka River estuary at Croatia by Cuculic et al. (2006) (45 – 662 Bq/kg).

Cores showed high variability of ^{226}Ra activities (Figure 4) which could likely due to the input of radioactivity from mainland, such as the usage of phosphate fertilizer in agriculture. Transported radionuclides eluted from soil and contained in dry and wet atmospheric precipitation (^{210}Pb) are deposited together onto sediment (Skwarzec and Jahnz, 2007). Ra-226 was found to have poor correlation with the particle size fraction or organic matter content. Only in the two cores collected during the dry season, the ^{226}Ra activities were found significant correlated with clay percentage (SP 01, $r = 0.44$ and SP 09, $r = 0.65$, $p < 0.05$) and in SP 09 there was also having a significant correlation with organic matter ($r = 0.92$, $p < 0.05$) (Table 4). This could be because of the inner river sediment received more input of ^{226}Ra from the mainland due to soil erosion, and as radium is soluble in water, thus, as fluvial sediments leached by heavy downpour during raining season, radium isotopes desorb owing to ion exchange competition with the major cations present in water (Li et al., 1977).

Table 3: Radioactivity concentrations of ^{137}Cs, ^{226}Ra, ^{210}Pb, ^{210}Pb excess and sediment accumulation rate at study site

Sampling Station	Activity Concentration (Bq/kg dw.)			Pb-210 Excess (Bq/kg dw.)	Sedimentation Accumulation Rate (cm/y)
	^{137}Cs	^{226}Ra	^{210}Pb		
SP 01	< MDA	54.0 – 209.9	78.8 – 241.0	5.9 – 142.0	0.94 ± 0.11
SP 03	< MDA	39.5 – 220.7	73.4 – 270.4	23.6 – 68.0	4.91 ± 1.26
SP 06	< MDA	26.2 – 65.0	58.6 – 93.1	10.8 – 49.6	4.83 ± 0.86
SP 09	< MDA	35.8 – 131.0	62.5 – 250.3	10.4 – 131.4	1.79 ± 0.49

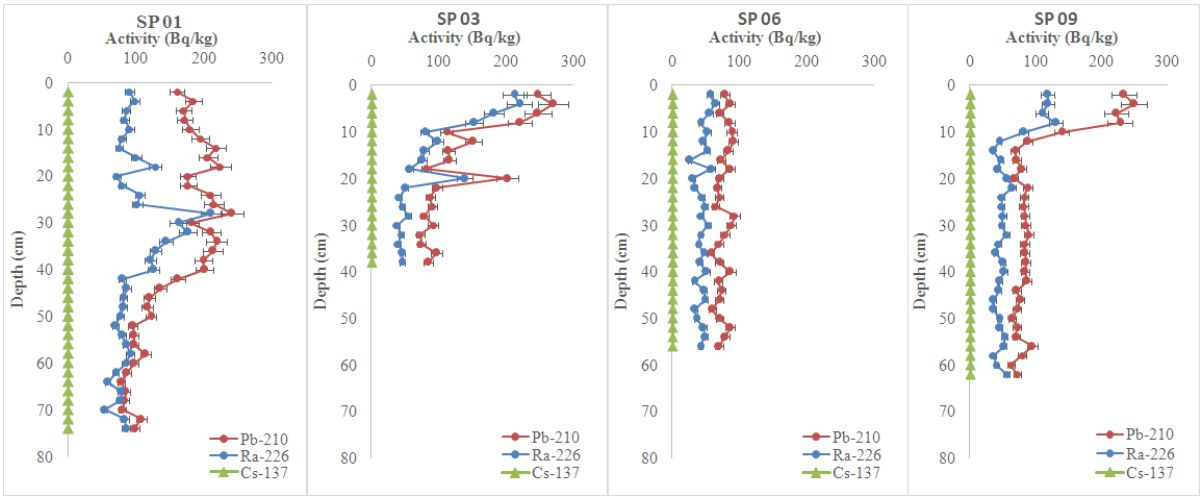

Figure 4: Activity concentrations of ^{137}Cs, ^{210}Pb and ^{226}Ra in sediment core at study site

Activities of ^{210}Pb were also higher than those previously reported in the region such as at Linggi river Estuary (south west Peninsular Malaysia), 37.9 – 176.2 Bq/kg (Wan Mahmood et al., 2016), at Kuala Muda area (North West Peninsular Malaysia), 11.9 – 78.8 Bq/kg (Yii et al., 2010) and at Brunei Bay, 2.6 – 32.3 Bq/kg (Joseph et al., 2018). The single factor ANOVA analysis revealed that there were no significant different between cores for the ^{210}Pb activities from Juru River: SP 01 (154.7±51.5 Bq/kg) = SP 03 (134.0±67.3 Bq/kg) and Perai River: SP 06 (76.8±9.6 Bq/kg) = SP 09 (100.9±54.1 Bq/kg).

Table 4: Summary of correlation analysis of radioactivity concentrations with the percentage of organic matter and particle size fractions in sediments from Juru and Perai Rivers, Malaysia

Station	Radionuclides	Correlation Coefficient (r)			
		Organic (%)	Clay (%)	Silt (%)	Sand (%)
SP 01	^{210}Pb	**0.56**	**0.44**	0.11	**-0.45**
	^{226}Ra	-0.02	**0.44**	0.05	-0.41
	^{210}Pb$_{ex}$	**0.76**	0.21	0.11	-0.25
SP 03	^{210}Pb	0.25	**-0.87**	**0.64**	-0.22
	^{226}Ra	0.27	**-0.88**	**0.68**	-0.25
	^{210}Pb$_{ex}$	0.02	-0.40	0.15	0.06
SP 06	^{210}Pb	-0.02	-0.15	-0.12	0.18
	^{226}Ra	-0.06	0.14	0.28	-0.27
	^{210}Pb$_{ex}$	0.03	-0.28	**-0.38**	**0.43**
SP 09	^{210}Pb	**0.93**	**0.72**	**-0.45**	**-0.36**
	^{226}Ra	**0.92**	**0.65**	**-0.41**	-0.33
	^{210}Pb$_{ex}$	**0.87**	**0.73**	**-0.46**	**-0.37**

Note: r values in Bold are significant at 95%, "-"value indicate negative correlation

The activities of ^{210}Pb were mostly higher than ^{226}Ra along all cores, and the equilibrium between both radionuclides was only achieved at cores SP 01 and SP 09. Nevertheless, significant correlations ($p < 0.05$) were observed between ^{226}Ra and ^{210}Pb activities (Figure 5) in all sediment cores collected (SP 01, r = 0.67; SP 03, r = 0.98; SP 06, r = 0.47 and SP 09, r = 0.96) suggesting most of the ^{210}Pb were coming from ^{226}Ra decays. The excess ^{210}Pb (^{210}Pb$_{ex}$) activities were calculated by subtracting the ^{226}Ra activities values from the ^{210}Pb activities values (Table 3). Pb-210$_{ex}$ activities were found to be significantly ($p < 0.05$) correlated with organic carbon content for cores collected during the dry season (r = 0.76 in SP 01; r = 0.87 in SP 09). No significant correlations ($p < 0.05$) were observed between ^{210}Pb$_{ex}$ and clay content in most cores except core SP 09 (r = 0.73). It has been shown that ^{210}Pb may be associated with biogenic particles and high ^{210}Pb activities may be derived from the lithogenic (detrital) inclusion (Bralower and Thierstein, 1987). As ^{210}Pb is a highly particle reactive and is readily scavenged by organic matter and clay size particles (Ontiveros-Cuadras et al., 2012), but under anoxic conditions, ^{210}Pb can be released back to the water (Benoit, 1988).

The logarithmic values of ^{210}Pb$_{ex}$ activity depth profiles in all cores evidenced significant departures from linearity (Figure 6), characteristics of a profile resulting only from radioactive decay, in aquatic environments where steady state sedimentation process occur. In most cases, such divergences could be the result of strong variations in the sediment accumulation process, sediment sources and mixing (UNESCO, 1978). As described previously, ^{210}Pb$_{ex}$ activities in the cores of this study were strongly influenced by the variations in grain size, and organic matter content. In addition, the uppermost 20 cm segment in core SP 01 showed ^{210}Pb$_{ex}$ activities decreasing upward

near the surface, which could have resulted from the accumulation of $^{210}Pb_{ex}$-depleted (older) sediments, from the dilution of $^{210}Pb_{ex}$ activities by high sediment loads, or from the accumulation of sediments from a different source (as suggested by the changes in particle size distribution (Figure 2); whereas between 20 and 40 cm depth, where $^{210}Pb_{ex}$ activities are almost homogeneous, the sediments might be mixed, although, looking at the high ^{226}Ra activities in this segment, likely this core segment accumulated sediments from a different source. Core SP 03 and SP 06 showed almost homogenous $^{210}Pb_{ex}$ activities throughout the cores which could due to the massive mud transportation into the river sediment by the heavy downpour during rainy season and the water turbulence that disturb the sediment surface. On the other hand, the sediments in the uppermost ~12 cm segment of core SP 09 seems to have been transported from a difference source (as indicated by the higher ^{226}Ra activities and high content of clay) and $^{210}Pb_{ex}$ activities near the surface were nearly homogenous.

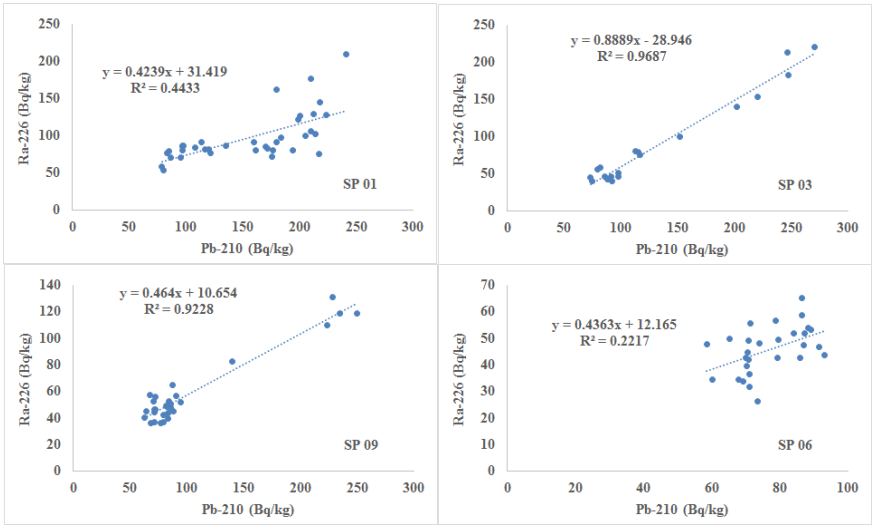

Figure 5: Correlation between ^{226}Ra and ^{210}Pb activities at study area

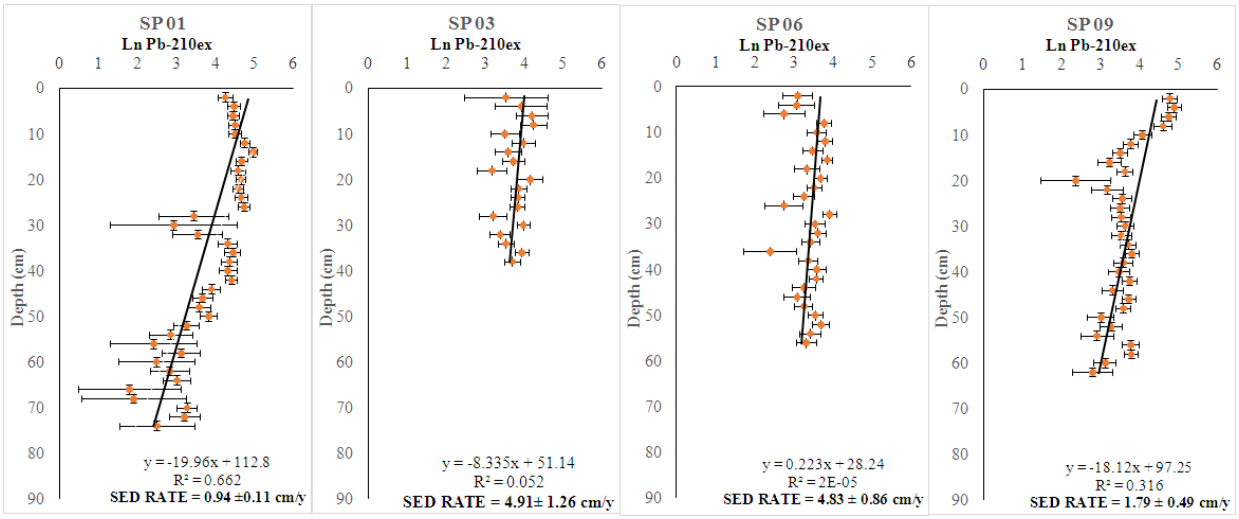

Figure 6: Sedimentation rates in core sediment at study site

The $^{210}Pb_{ex}$ activities were normalized by the organic matter and clay content in the cores, with the purpose to evaluate if the $^{210}Pb_{ex}$ profile could be the improved; however, results were not satisfactory. Nonetheless, despite all the complex features observed in the $^{210}Pb_{ex}$ activity depth profiles, all of them showed significant ($p < 0.05$) decreasing trends with depth, with high slope values, which would account for high sediment accumulation rates (Alongi et al., 2005); although, owing to the non-monotic $^{210}Pb_{ex}$ depth profiles, it is very difficult to derive an age model from them. However, by using the constant rate-constant sedimentation (CF-CS) model (Krishnaswamy et al., 1971), which assumes a constant $^{210}Pb_{ex}$ flux to the sediment surface and a sediment accumulation rate (Sanchez-Cabeza and Ruiz-Fernández, 2012), attempts were made to approximate a preliminary mean sedimentation rate for each core. Thus, the logarithm of excess ^{210}Pb (ln $^{210}Pb_{ex}$) data obtained in this study was plotted against the depth of sediment core; and the slope of the regression between both variables was used to estimate the mean sediment accumulation rate (SAR, in cm/y). The mean SAR values obtained (Table 3) was 0.94±0.11 cm/y in SP 01, 4.91 ± 1.26 in SP03, 4.83±0.86 cm/y in SP06 and 1.79±0.49 cm/y in SP09. As expected, the accumulation rates in the rainy seasons (SP 03, SP 06) were much higher than those during the dry seasons (SP 01, SP 09). At Juru River, the SAR value during rainy season almost five folds when compared to the dry season and at Perai River, it was 2.5 times higher.

The mean sediment accumulation rate for Juru and Perai River was 0.94 cm/y and 1.79 cm/y, respectively during the dry season were found comparable to those reported by Joseph et al. (2018) for Brunei Bay where the sedimentation rates ranged between 0.47 – 2.13 cm/y and higher sedimentation was attributed to rapid of urban and industrial development. This study results were also comparable to the sedimentation rates found at Linggi River estuary between 0.70 – 1.97 cm/y (Wan Mahmood and Yii, 2013). However, sediment accumulation rate found in this study was higher than some other areas as reported by Cheevaporn et al. (1994) at Bang Pakong River, Thailand (0.47 – 0.72 cm/y), and by Xu et al. (2008) at Nile River delta, Egypt (0.42 – 0.56 cm/y).

CONCLUSIONS

Two sediments cores were collected from each Juru River and Perai River located in Penang's Perai Industrial Area during two different season and analyzed using nuclear techniques, with the purpose to evaluate the sediment accumulation rates at the study area. Using the gamma spectrometry, ^{137}Cs, ^{210}Pb and ^{226}Ra activity profiles were established for each core; however, owing to the complexity of the excess ^{210}Pb activity profiles obtained, it was not possible to obtain an age model from them. However, preliminary accumulation rates for the sediment were estimated and found to be within 0.94 – 4.91 cm/y. The highest sediment accumulation rate was found in core SP 03 that collected at Juru River during the rainy season. Based on the estimated sediment accumulation rates found in this study, it can be concluded that the deposition rates for sediments during the rainy season at Juru River and Perai River was 5 times and 2.5 times higher, respectively, as compared to that of the dry season.

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