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CONCENTRATION OF NATURAL RADIOACTIVITIES ^{226}Ra, ^{232}Th AND ^{40}K IN RIVER SEDIMENTS AT PERAI INDUSTRIAL AREA, MALAYSIA AND THE ASSOCIATED RADIOLOGICAL RISK

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ABSTRACT

Sediment samples were collected from two rivers at the Perai Industrial area, which is one of the dense populated major industrial parks in Malaysia. The activity concentrations of the NORM members i.e. ^{226}Ra, ^{232}Th and ^{40}K were measured using HPGe gamma spectrometer after achieving 30 days secular equilibrium with their progenies. The radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K ranged from 43.4 to 268.0 Bq kg^{-1}, from 69.4 to 312.0 Bq kg^{-1} and from 181.8 to 777.2 Bq kg^{-1}, with an average value of 114.6±11.4 Bq kg^{-1}, 155.0±12.5 Bq kg^{-1}, and 504.6±59.7 Bq kg^{-1}, dry weight, respectively. Several radiation hazard indices were calculated to evaluate the radiological risk for the public. The average values of radium equivalent activity (Ra_{eq}) were 375.1 Bq kg^{-1}. Meanwhile, the average values for External (H_{ex}) and Internal (H_{in}) radiation hazard index were 1.0 and 1.3, respectively. Both Ra_{eq} and H_{in} were higher than the safety recommended value of 370 Bq kg^{-1} and unity, respectively. Moreover, the average values of gamma absorbed dose rate (D) in the air were 167.6 nGy h^{-1}, which was also higher than the world average values reported by UNSCEAR but the average estimated annual effective dose (AED) values were only 205.6 μSv y^{-1}, that was below the annual public dose of 1,000 μSv y^{-1} as recommended by ICRP for public radiological safety.

Keywords : Radioactivity concentration, gamma spectrometer, radiation hazard indices, annual effective dose

INTRODUCTION

In the environment, natural radioactivity is widely spread and present in several geological formations such as in the air, mineral, plant, rock, soil and sediment that acts as one of the dominant sources to the background radiation (Lu et al., 2008; UNSCEAR, 2000; Yang et al., 2005). Evaluation of the radioactivity level and its radiological health hazard can therefore provide important information for the protection of the general public against radiation exposure (Kasoga et al., 2015). Naturally occurring radioactive material (NORM) can be found in the crust layer of the earth such as in minerals, rocks, sediments and soils became the main terrestrial radiation source received by humans. The NORMs which are derived fundamentally from ^{40}K ($T_{1/2}$ = (1.277±0.008) x 10^9 y) and the daughters of ^{238}U ($T_{1/2}$ = (4.468±0.005 x 10^9 y) and ^{232}Th ($T_{1/2}$ = (1.405±0.006) x 10^{10} y) decay series such as radium, radon, lead, bismuth and polonium. These progenies first appear in the geosphere level, then deposited on the surface soil before they been washed and drained through several pathways such as weathering, erosion, fallout, rainwater and human activities into rivers transport going into the estuary and finally ended up in the

marine environment and deposited in waters, sediments and biota (Abdul-Rahman et al., 2004; Akram et al., 2004).

Contamination of the aquatic environment by radioactive materials may finally end up contributing ingestion doses to the human being through three pathways: i.e. drinking of freshwater from both surface and ground sources, consumption of living biota especially fishes in the water, and consumption of contaminated terrestrial foods due to the use of freshwater for irrigation, or by the application of sediments as soil conditioners, or by the application of aquatic plants as fertilizer. Consuming the contaminated water by animals may also form a pathway where radionuclides will be accumulating to the human. Moreover, the deposition of contaminated sediments at shoreline can also contribute to external exposures (IAEA, 1989; UNSCEAR, 2000).

Sediment formed from complex materials contributed by rivers, coastal erosion, biological and chemical processes, as well as from the anthropogenic waste. Weathering has always been the main source of sediments, while the rapid economic growth and settlement development also release waste materials into the coastal area and all these accumulated into the sediment (Joseph et al., 2018). Sediments settle in rivers are mainly composed of sands, clays and silts that derived from weathering erosion of terrestrial rocks and soils. Therefore, the concentration of the natural radionuclides in terrestrial rocks and soils would indirectly affect the radioactivity levels of river sediments (Lu et al., 2008).

Perai Industrial area is one of the major industrial parks in Malaysia which is adjacent by Juru River located at the east of the area, Perai River to the northwest and Straits of Malacca on the west. Perai Industrial area is also densely populated and comprises of lots of multiple heavy industrials. 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 & Masque, 2004).

The aim of this study is to determine the natural radioactivity of ^{226}Ra ($T_{1/2}$ = 1600±7 y), ^{232}Th and ^{40}K concentration levels in the river sediment samples collected from the two rivers at the Perai Industrial area and assessing their potential radiological risks. A total of twenty-four samples were measured in this study under the same counting conditions by using the same single spectrometer.

MATERIALS AND METHODS

Samples collection and preparation

Surface sediment samples were collected on July 2018 (dry season) from accessible locations (Fig. 1 and Table 1) at the Juru river and Perai river (and their main subsidiary river) of the Perai Industrial area, Malaysia. Salinity and pH of the river water at sampling station were also recorded during sampling. From each station, approximately one (1) kg of sample was taken using Ekman grab sampler and placed into HDPE plastic bag, properly sealed and labelled before brought back to the laboratory for further analysis. Back in the laboratory, small portions of samples were taken for particle analysis, the remaining samples were weighed and dried in an oven at 80 ^{o}C until constant weight (IAEA, 2003).

The dried samples were finely ground using a Rocklabs® grinder mill to obtain homogeneous powders of less than 200 mesh size (74 µm). The sample was transferred and compressed into a 250 ml size Marinelli beaker (actual measured volume is 320 ml), sealed with thick PVC tape to inhibit radon gas from escaping (Yii, 2019; Zal U'yun et al., 2017). The samples weight between 250–500 g with a density between 0.78–1.56 g ml^{-1}. All data in this study was reported on a dry weight basis. All samples were stored for a period in excessive of 30 days to establish secular equilibrium between ^{226}Ra (^{238}U) and ^{232}Th with their progenies (Dowdall & O'Dea, 2002; Kolapo, 2014; Yang et al., 2005).

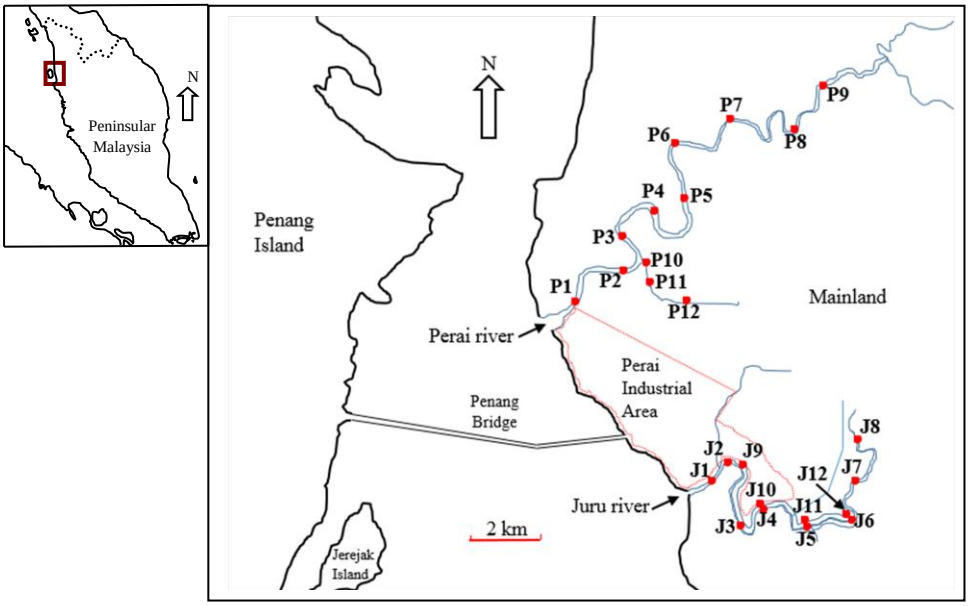

Figure 1: Sampling locations

Table 1: Coordinate of sampling locations

Station	Longitude ºE	Latitude ºN	Station	Longitude ºE	Latitude ºN
J1	100.4084	5.3406	P1	100.3774	5.3896
J2	100.4135	5.3477	P2	100.3893	5.3958
J3	100.4176	5.3308	P3	100.3860	5.4055
J4	100.4274	5.3360	P4	100.3948	5.4133
J5	100.4353	5.3305	P5	100.4039	5.4147
J6	100.4455	5.3323	P6	100.4007	5.4292
J7	100.4486	5.3427	P7	100.4171	5.4349
J8	100.4483	5.3515	P8	100.4311	5.4312
J9	100.4193	5.3463	P9	100.4382	5.4425
J10	100.4272	5.3368	P10	100.3932	5.3989
J11	100.4346	5.3317	P11	100.3944	5.3937
J12	100.4453	5.3326	P12	100.4032	5.3882

Particle Analysis, gamma counting and activity calculation

Particle size distribution analysis was performed as described in Yii et al. (2020). Meanwhile, measurements of ^{226}Ra, ^{232}Th and ^{40}K were performed using the same unit of Gamma spectrometry system. Setup of the counting system, calibration, counting conditions, activities calculation, and the minimum detected activity (MDA) used in this study were similar to those described in the previous paper (Yii, 2019). IAEA's reference materials of IAEA-Soil-6, IAEA-315 and IAEA-326 were used for quality control evaluation. The results of samples were accepted if the measured reference materials values were within the 95% confidence interval as mentioned inside the certificates. Statistical analysis approach as described in the previous paper by Yii et al. (2020) was used to explain the relationship among parameters.

Calculation of radiological indices

The radiological indices calculated in this study consist of several parameters. Among these are:

(i) *Radium equivalent activity concentration index, Ra_{eq}*

Radium equivalent activity concentration index with a symbol of Ra_{eq} is among well known and most widely used to estimate radiation hazard index or radiation hazard parameter or radiological index. In this estimation, the specific activities of radium, thorium and potassium in different combinations in sediment samples were compared, where Ra_{eq} is defined by Beretka & Mathew (1985), as below:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad \text{eq (1)}$$

where, A_{Ra}, A_{Th} and A_K are the specific activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K (in Bq kg^{-1}), respectively. This equation is based on the estimation that 1 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K generate the same γ-ray dose rate (Ahmed & El-Arabi, 2005; Stranden, 1979; Yang et al., 2005). To be non-hazardous, the calculated Ra_{eq} value should not exceed a maximum value of 370 Bq kg^{-1} as reported in UNSCEAR (1982).

(ii) *External and Internal radiation hazard indices, H_{ex} and H_{in}.*

External and internal radiation hazard indices are commonly used to reflect both external and internal exposure of the additional radiological hazard on the people which are daily exposed to the natural gamma radiation (Krieger, 1981). The radiation hazard indices can be calculated using the following equations:

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \text{eq (2)}$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \text{eq (3)}$$

where, A_{Ra}, A_{Th} and A_K are the activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. The value of the indices should be ≤ 1 in order to be considered as non-hazardous (Krieger, 1981).

(iii) *The total air absorbed dose rate*

The total air absorbed dose rate, D (nGy h^{-1}) due to the average activity concentrations of $^{238}U(^{226}Ra)$, ^{232}Th and ^{40}K in Bq kg^{-1} is estimated using the equation given by Sheela and Shanthi (2016), UNSCEAR (2000; 2008) (UNSCEAR., Sources, Effects and Risks of Ionizing Radiation 2000, UNCEAR 2008) and Venkidasamy et al. (2011) (Venkidasamy 2011).

$$D = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad \text{eq (4)}$$

where, A_U, A_{Th} and A_K are the activity concentrations for ^{238}U (^{226}Ra), ^{232}Th and ^{40}K in Bq kg^{-1}, respectively. Sheela & Shanthi (2016) derived this equation for calculating the total air absorbed dose rate in air at height of 1.0 m above from the ground that measured the activity concentrations for uniform distribution of naturally occurring radionuclides in the environmental materials.

(iv) *Annual effective dose rate (AED)*
In order to calculate the annual effective dose rates (μSv y^{-1}) from the total air absorbed dose rate, D (nGy h^{-1}), the total yearly hour (8760 h y^{-1}), the conversion coefficient of the absorbed dose in the air (0.7 Sv Gy^{-1}) and the outdoor occupancy factor (0.2) is used (UNSCEAR, 2000). The AED is presented as

$$AED = D \times 8760 \times 0.7 \times 0.2 \times 10^{-3} \quad \text{eq (5)}$$

RESULTS AND DISCUSSION

Activity concentration of radionuclides in sediment samples

The activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in sediment samples at different locations in the study area were presented in Figs. 2-4. The activity concentration of ^{226}Ra in sediment samples were ranged from 43.4 Bq kg^{-1} to 268.0 Bq kg^{-1} with an average of 124.6±8.3 Bq kg^{-1} and from 43.4 Bq kg^{-1} to 167.8 Bq kg^{-1} with an average of 104.5±7.9 Bq kg^{-1}, for Juru river and Perai river, respectively. A single factor ANOVA analysis revealed that ^{226}Ra activities were no significant differences between samples from the two rivers. Highest concentration for ^{226}Ra was found at station J8 (upstream) which was six times higher than the lowest concentration of ^{226}Ra found at the river mouth J1 station. Meanwhile for ^{232}Th, values were varied from 89.8 Bq kg^{-1} to 312.0 Bq kg^{-1} (average 166.8±9.4 Bq kg^{-1}) and 69.4 Bq kg^{-1} to 211.1 Bq kg^{-1} (average 143.3±8.2 Bq kg^{-1}), for Juru river and Perai river, respectively. Again, the single factor ANOVA analysis revealed that ^{232}Th activities between samples from the two rivers were also not significantly different. Highest concentration for ^{232}Th also found at station J8 which was 3.5 times higher than the lowest concentration, again at station J1. Lastly, the activity concentration of ^{40}K in sediment found to vary from 339.0 Bq kg^{-1} to 777.2 Bq kg^{-1} and 181.8 Bq kg^{-1} to 767.3 Bq kg^{-1}, for Juru river and Perai river, respectively. As the same to the others two radionuclides, single factor ANOVA analysis for ^{40}K again revealed that there were also no significant difference between the samples activities from the two rivers (average ^{40}K, Juru river: 485.3±41.1 Bq kg^{-1}; Perai river: 523.9±43.3 Bq kg^{-1}). Station J8 once again showed the highest concentration of ^{40}K and the value almost four times higher than the values of the lowest concentration found at station P12.

In this study, it was found that the concentration of ^{40}K accounted for approximately 40 – 80% of the total gamma activity of the sediment samples from the study area and served as the biggest contributor to the total activity for all the samples. The high concentrations of NORMs at station J8 could be caused by nearby activities such as usage of artificial phosphate fertilizers in agricultural production. Several researches reveal a high concentration of NORMs were found in the phosphate fertilizers. For instance, 1852 Bq kg^{-1} of ^{226}Ra was found in fertilizer used at Israel (Olszewska-Wasiolek, 1995); 521 Bq kg^{-1} of ^{228}Ra was found in fertilizer used at Brazil (Saueia & Mazzilli, 2006); 4000 Bq kg^{-1} of ^{40}K was found in fertilizer used at Italy (Righi et al., 2005). Another potential source of radionuclides could be coming from the releases by nearby factories processing NORMs materials such as concretes, cements, plasters, quarries, etc.

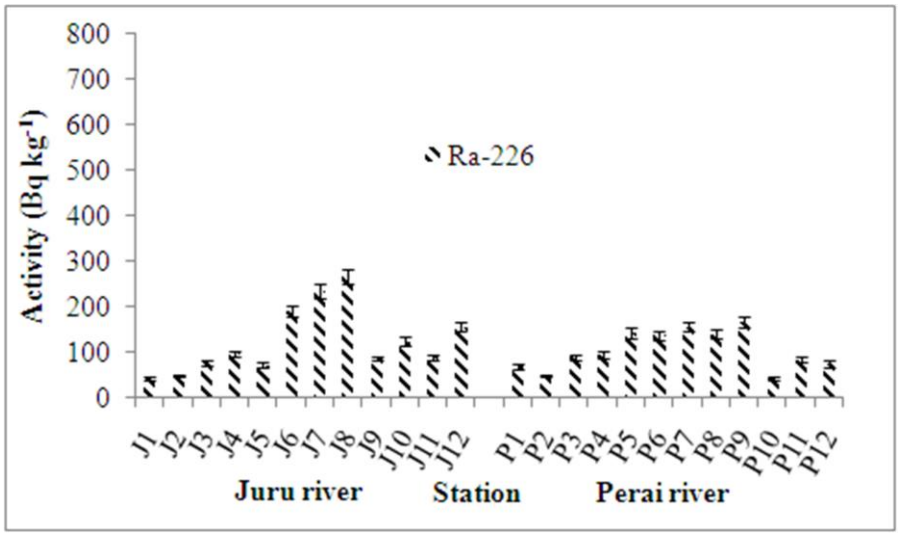

Figure 2: Comparison of the activity concentrations of ^{226}Ra from two rivers in the sediment samples

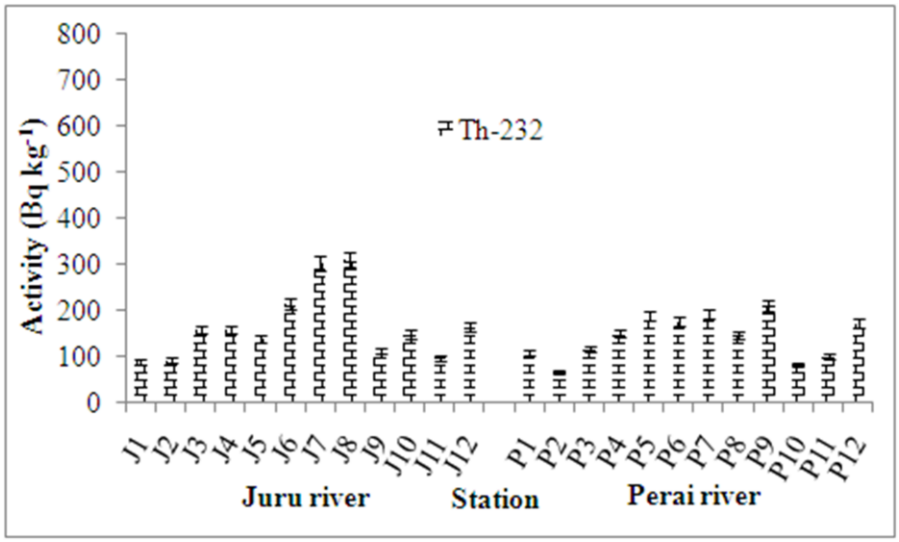

Figure 3: Comparison of the activity concentrations of ^{232}Th from two rivers in the sediment samples

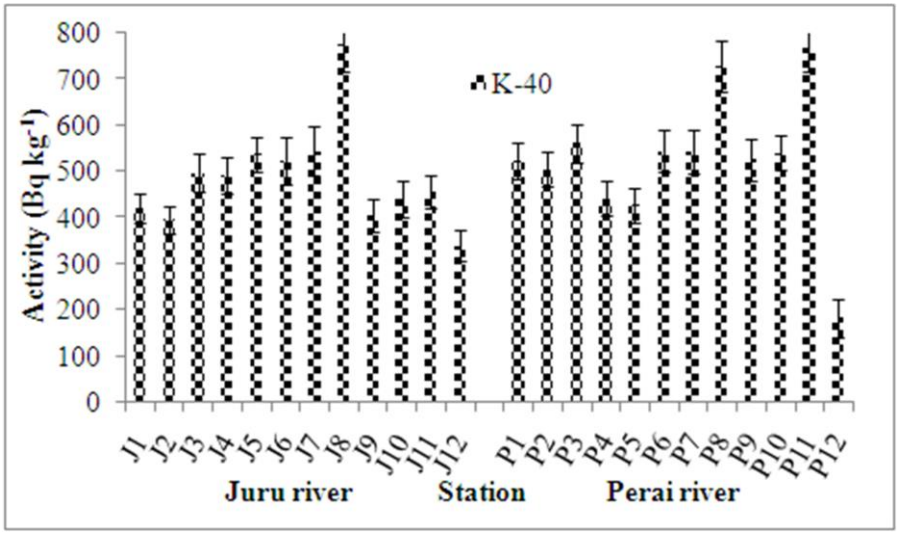

Figure 4: Comparison of the activity concentrations of ^{40}K from two rivers in the sediment samples

Generally, radioactivities found in both rivers showing a decreasing pattern from upstream towards downstream which may suggest the radioactivities were originated from the run-off of soil and others terrestrial sources at the upstream river (J8 and P9). Usually, the inner river sediment received more input of radionuclides from the mainland due to soil erosion, and as radium and potassium are readily soluble in water, thus, as fluvial sediments leached by the massive volume of river water, radium and potassium isotopes will desorb owing to ion exchange competition with the major cations present in water (Li et al., 1977). The decrease may also due to the increase in salinity (Fig. 5) in the transition from river to the sea causes desorption of radionuclides from sediments (UNSCEAR, 2000). Meanwhile, no clear relation was found between pH (Fig. 5) and the radioactivities. Overall, the average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the twenty-four river sediment samples were 114.6±11.4 Bq kg^{-1}, 155.0±12.5 Bq kg^{-1}, and 504.6±59.7 Bq kg^{-1}, dry weight, respectively.

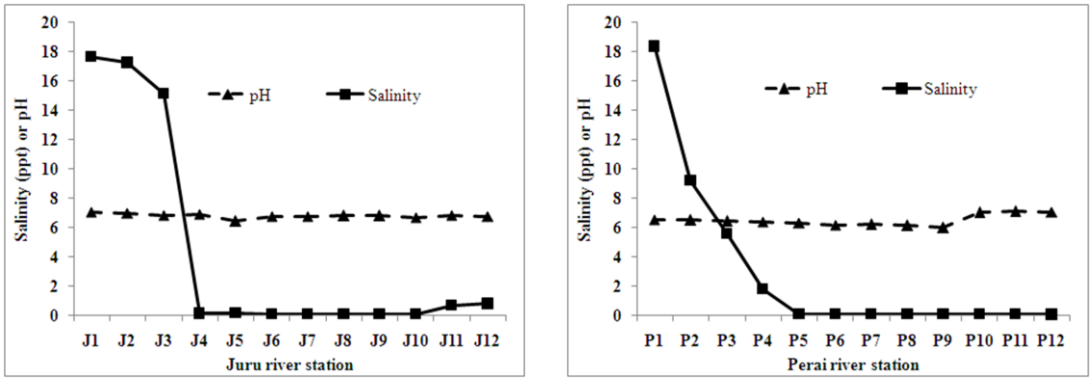

Figure 5: Salinity and pH at Juru (left) and Perai (right) rivers sampling station

Wide range of radioactivity level found in this study where some locations appeared to be higher than the others and generally Juru river's sediment radioactivity values were higher than that from Perai river. The origin of various types of terrestrial rocks and soils as well as their geochemical composition may be the main reason for this difference such as run-off from rocks and soils that are radioactive-rich like granite, phosphate, sandstone and quartzite (Dabayneh et al., 2008; Thabayneh & Jazzar, 2012; UNSCEAR, 1993; UNSCEAR, 2000). Moreover, the Perai river is much bigger than the Juru river, this could also cause faster run-off of radionuclides from the sediments.

The correlation between radionuclides in sediment samples was computed from the concentrations of these radionuclides. Significant correlations ($p<0.05$) were found among radionuclides in Juru river sediment (^{226}Ra-^{232}Th, $r = 0.95$; ^{226}Ra-^{40}K, $r = 0.66$; and ^{232}Th-^{40}K, $r = 0.76$) but in Perai river, only ^{226}Ra and ^{232}Th radionuclides was found significant correlated ($r = 0.87$, $p<0.05$). Overall for all the sediment samples, only ^{226}Ra and ^{232}Th radionuclides was found significant correlated ($r = 0.93$, $p<0.05$).

When comparing the results with other studies, the activity concentrations of radionuclides measured in the present work were higher than values for Malaysia's soil (UNSCEAR, 2000) but the results were still within the range of values as reported for worldwide and other countries that summarized in Table 2. Observation revealed that the measured activity concentration of ^{40}K significantly exceeded other natural radionuclides in most locations. This showed that ^{40}K is a more abundance radionuclide as compared to other radionuclides in the soils (Thabayneh & Jazzar, 2012). Meanwhile, ^{232}Th activity values were found to be higher concentrations than ^{226}Ra at all stations in the study area and these agreed with the other findings that Malaysian's soils contenting more thorium than uranium (UNSCEAR, 2000). As sediments were mainly originating from terrestrial soils and therefore radioactivity concentration values from the soil were also can be used for comparison.

Table 2: Comparison of radioactivity concentrations for ^{226}Ra, ^{232}Th and ^{40}K in soil and sediment from various locations.

Location	**Level**	**Activity concentration of radionuclides (Bq kg^{-1})**		
		^{226}Ra	**^{232}Th**	**^{40}K**
This study	Minimum	43.4	69.4	181.8
	Maximum	268.0	312.0	777.2
	Average	114.6	155.0	504.6
Accra coast sediment, Ghana (Amekudzie, 2011)	Minimum	0.6	0.2	8.6
	Maximum	148.8	732.6	61.0
	Average	22.0	108.6	29.8
Alexandria–Rosetta coast sediment, Egypt (Abdel-Halim & Saleh, 2016)	Minimum	12.6	0.7	-
	Maximum	499.2	386.2	-
	Average	-	-	-
Gwadar coast sediment, Pakistan (Akram et al., 2004)	Minimum	16.9	9.8	152.4
	Maximum	31.7	13.3	244.4
	Average	24.3	11.7	227.0

Malaysia coast sediment (Mohamed et al., 2010)	Average	27.7	73.3	-
Saudi Arabia coast sediment (Alshahri, 2017)	Minimum	18.3	7.8	202
	Maximum	37.6	25.5	432
	Average	26.4	16.3	351
Tamilnadu coast sediment, India (Sankaran et al., 2018)	Average	58.8	465.2	311.2
Al-Husseiniya river sediment, Iraq (Al-Alawy et al., 2018)	Minimum	12.5	8.3	252.4
	Maximum	18.0	13.3	341.0
	Average	15.8	11.2	311.0
Kallada river sediment, India (Venunathan et al., 2016)	Average	48.6	88.0	423.2
Langat and Semenyih river sediment, Malaysia (Phuah et al., 2004)	Minimum	18.9	12.6	-
	Maximum	236.1	410.6	-
	Average	-	-	-
Maritza river sediment, Turkey (Aytas et al., 2012)	Average	219	128	298
Tundja river sediment, Turkey (Aytas et al., 2012)	Average	186	121	222
Nile river sediment, Egypt (El-Gamal et al., 2007)	Minimum	3.8	2.9	112
	Maximum	34.9	30.1	313
	Average	16.3	12.9	200
Northern Pakistan river sediment (Qureshi et al., 2014)	Minimum	21.4	11.7	174.0
	Maximum	110.5	172.1	825.4
	Average	50.7	70.2	531.7
Ponnaiyar river sediment, India (Ramasamy et al., 2009)	Average	7	47	384
Thamirabarani river sediment, India (Thangam et al., 2020)	Average	40.9	51.9	838.2
Wei river sediment, China (Lu et al., 2008)	Minimum	10.4	15.3	514.8
	Maximum	39.9	54.8	1175.5
	Average	21.8	33.1	833.3
Malaysia soil (UNSCEAR, 2000)	Minimum	38	63	170
	Maximum	94	110	430
	Average	67	82	310
Ulu Tiram soil, Malaysia (Abdul-Rahman & Ramli, 2007)	Minimum	21.9	43.5	-
	Maximum	57.6	334.1	-
	Average	45.7	175.0	-
Xiazhuang soil, China (Yang et al., 2005)	Minimum	61.6	61.6	509
	Maximum	442	87.8	883
	Average	112	71.5	672
Worldwide soil (UNSCEAR, 2000)	Average	35	30	400

Particle size analysis in sediment samples and their correlations with radionuclides

The sediments in all samples were mostly composed of fine-grained particles (Fig. 6). In most samples, the percentages of silts were higher than the clay, and the clays were higher than that of sands. Overall, for all the samples, the silts content around 35–80 %, the clays content between 10–50 % whilst the sands content around 0–50 %. Silts content showing an increasing pattern from upstream to downstream. These could be due to the re-suspension of the fine particle when the river water flows through the area. Meanwhile, the silts content was almost constant and only found low at some particular stations. On the other hand, sands content in sediments were generally low and only recording high values at some specific stations (J2, J11, P1, P8 and P11). Movement of sand might be related to direct erosion and run-off from nearby river activities and these very much depending on the volume and speed of water flow in the river. Correlation studies between particulate sizes with radionuclides (Table 3) found that only radionuclides in Juru river were significantly correlated with silt (^{226}Ra, r = 0.64; ^{232}Th, r = 0.72; ^{40}K, r = 0.65, P<0.05) while no other significant correlations were found.

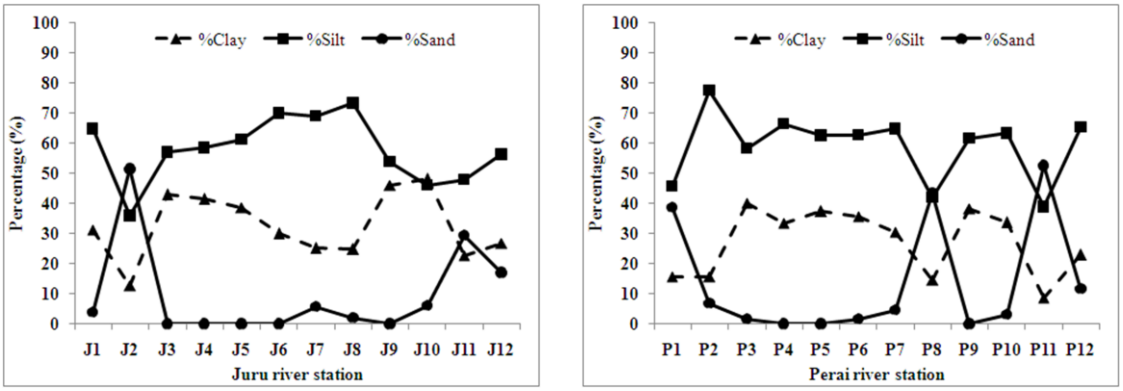

Figure 6: Particle size distributions in sediment at Juru (left) and Perai (right) rivers

Table 3: Summary of correlation analysis of radioactivities concentrations with the particle size fractions in sediments from Juru and Perai rivers, Malaysia

Station	Radionuclides	Particle size		
		Clay (%)	Silt (%)	Sand (%)
Juru river	**^{226}Ra**	-0.22	**0.64**	-0.29
	^{232}Th	-0.15	**0.72**	-0.39
	^{40}K	-0.08	**0.65**	-0.39
Perai river	**^{226}Ra**	0.38	-0.10	-0.16
	^{232}Th	0.51	0.12	-0.36
	^{40}K	-0.34	**-0.64**	0.57

Note: r values in bold are significant at 95%, "-" value indicates negative correlation.

Radiological hazard indices

The radium equivalent activity concentration index, Ra_{eq}, the external radiation hazard, H_{ex}, the internal radiation hazard, H_{in}, the total air absorbed dose rate, D, and the annual effective dose, AED, at each station in this study have been calculated using equations (1) to (5) above and tabulated in Table 4. The radium equivalent activity concentration index, Ra_{eq}, the external radiation hazard, $H_{ex,}$ and the internal radiation hazard, H_{in}, are radiological index, defined as radiation hazard indices which are used to assess the radiation hazard of the gamma ray due to the present of NORM radionuclides (Zal U'yun et al., 2017). The estimated values for Ra_{eq}, H_{ex} and H_{in} varied from 187.0 to 773.9 Bq kg^{-1} with the average value of 375.1 Bq kg^{-1}, between 0.5 to 2.1 with the average of 1.0 and from 0.6 to 2.8 (average value 1.3), respectively. About halves of the Ra_{eq} values were found to be exceeding the maximum safe value of 370 Bq kg^{-1} as recommended by UNSCEAR (1982) with 5 locations coming from each river (J6, J7, J8, J10, J12 of Juru river; P5 – P9 of Perai river). Similar observations were also found for the calculated H_{ex} values where the same 5 locations from each river were found having H_{ex} values > 1.

Meanwhile, calculated H_{in} values indicating that 16 out of the 24 stations having values more than unity with 8 locations coming from each river. In order to be considered as non-hazardous, the H_{ex} and H_{in} should be ≤ 1 as suggested by Krieger (1981). Thus, these findings reflected that the radiation hazards in the study area need to be taking of concern by the public. These showed that the natural radiations at some locations (base on radionuclide concentrations found in samples) are having potential adding extra radiation risks to the people within the study area if they are staying close to these stations, particularly when the river is shallow, especially during the dry season and not able to serve as natural radiation shielding from the riverbed sediments.

Table 4: Radium equivalent activity, external hazard index, internal hazard index, total air absorbed dose rate and annual effective dose at each sampling station.

Station	Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}	D (nGy h^{-1})	AED (μSv y^{-1})
J1	204.2	0.6	0.7	91.8	112.6
J2	213.1	0.6	0.7	95.6	117.3
J3	345.5	0.9	**1.1**	153.6	188.3
J4	364.0	1.0	**1.2**	162.1	198.8
J5	313.7	0.8	**1.0**	140.3	172.1
J6	**542.2**	**1.5**	**2.0**	241.4	296.1
J7	**711.3**	**1.9**	**2.6**	314.7	386.0
J8	**773.9**	**2.1**	**2.8**	344.6	422.7
J9	280.6	0.8	1.0	125.7	154.1
J10	**372.4**	1.0	**1.3**	166.3	203.9
J11	**265.4**	0.7	**1.0**	119.9	147.0
J12	**419.4**	1.1	**1.6**	186.4	228.6
P1	**265.3**	0.7	**0.9**	119.6	146.7

P2	**187.0**	0.5	**0.6**	85.5	104.9
P3	**300.1**	0.8	**1.1**	135.5	166.2
P4	**346.3**	0.9	**1.2**	154.1	189.0
P5	**447.4**	1.2	**1.6**	198.6	243.5
P6	**431.7**	1.2	**1.5**	192.8	236.5
P7	**474.4**	1.3	**1.7**	211.6	259.5
P8	**407.2**	1.1	**1.5**	184.2	226.0
P9	**510.2**	1.4	**1.8**	227.0	278.4
P10	**205.6**	0.6	**0.7**	93.5	114.7
P11	**286.5**	0.8	**1.0**	131.4	161.1
P12	**335.5**	0.9	**1.1**	146.4	179.5
Small	**187.0**	0.5	**0.6**	85.5	104.9
Large	**773.9**	2.1	**2.8**	344.6	422.7
Average	**375.1**	1.0	**1.3**	167.6	205.6
Std dev	**149.3**	0.4	**0.6**	65.8	80.7
Recommended safety value	**370**	1.0	**1.0**	-	1000

From the radioactivities values found in the study area, the calculated total air dose rate for the outdoor environment found to be varying from 85.5–344.6 nGy h^{-1} with an average value of 167.6 nGy h^{-1}. This value was found higher than the estimated average global terrestrial radiation of 55 nGy h^{-1} (range: 28 – 120 nGy h^{-1}), 59 nGy h^{-1} (range: 18 – 93 nGy h^{-1}) and 62 nGy h^{-1} as reported by UNSCEAR (1993), UNSCEAR (2000) and Hien et al. (2002), respectively, and also higher than values of 55 – 130 nGy h^{-1} (average: 92 nGy h^{-1}) for Peninsular Malaysia (UNSCEAR, 2000), and 2 – 100 nGy h^{-1} (average: 77 nGy h^{-1}) for Thailand (UNSCEAR, 2000). However, this value was lower when compared to the value recorded in Ulu Tiram soil which ranging between 96 – 409 nGy h^{-1} (average: 200 nGy h^{-1}) (Abdul-Rahman & Ramli, 2007), Tamilnadu coast sediment (30 – 8700 nGy h^{-1}) (Sankaran et al., 2018) and also at Turkey's river sediments (169 – 191 nGy h^{-1}) (Aytas, 2012).

The radiological indices or radiation hazard parameters at some locations in the study area found exceeded the UNSCEAR's recommended values could be due to the natural occurrence of a relatively high activity concentration of natural radionuclides in the sediment at the particular locations (J6, J7, J8, J10, J12 of Juru river; P5 – P9 of Perai river). The station J8 (upstream Juru river) was found to give the highest radiation risk to people while the lowest radiation risk station was at station P2 (downstream Perai river).

The estimated annual effective dose (AED) values to an individual exposed to the river sediment were ranged between 104.9 – 422.7 μSv y^{-1} with average dose equivalent at 205.6 μSv per year (0.1 – 0.4, average 0.2 mSv y^{-1}). This value was slightly below the worldwide average annual effective dose for external exposure from the terrestrial gamma rays (0.3 – 0.6, average 0.5 mSv y^{-1}) by UNSCEAR (2000) and also lower than the International Commission on Radiological Protection (ICRP) recommended maximum annual dose limit of 1.0 mSv y^{-1} to members of the public (ICRP, 1995). The calculations were performed using assumption as described in the equation (5) above.

The results for the radium equivalent activity, external and internal hazard indices, total air dose rate and annual effective dose of the present work and other studies were compared in Table 5. It was found that, in general, the values of Ra_{eq}, H_{ex}, H_{in}, D, calculated for the sediments in this study were higher than those reported elsewhere and at certain locations more than the recommended safety figures, indicating that there was the potential additional risk of radiation exposure to the people in this vicinity. Safety precautions shall be taken to reduce the exposure to the radiation and continuous monitoring were required in the study area to ensure the safety of people.

Table 5: Comparison of radium equivalent activity, external hazard index, internal hazard index, total air absorbed dose rate and annual effective dose of the present work and other studies.

Location/ Country	**Sample**	**Ra_{eq} (Bq kg^{-1})**	**Hex**	**Hin**	**D (nGy h^{-1})**	**AED (uSv y^{-1})**	**Reference**
Accra coast, Ghana	Sediment	9.0	0.5	0.5[a]	77.0	90	Amekudzie, 2011
Alexandria–Rosetta coasts, Egypt	Sediment	183.9	1.3	-	82.5	100	Abdel-Halim & Saleh, 2016
Gwadar coast, Pakistan	Sediment	57.9	0.2[a]	0.2[a]	27.1	30	Akram et al., 2004
Saudi Arabia coast	Sediment	78.1	0.2	0.3[a]	36.7	45	Alshahri, 2017
Tamilnadu coast	Sediment	-	-	-	30 - 8700	290 - 12800	Sankaran et al., 2018
Al-Husseiniya river, Iraq	Sediment	56.0	0.2	0.2	27.5	34	Al-Alawy et al., 2018
Kallada river, India	Sediment	207.0	0.6	0.7	95	114	Venunathan et al., 2016
Maritza river, Turkey	Sediment	425.0[a]	1.1[a]	1.7[a]	191	2000	Aytas et al., 2012
Tundja river, Turkey	Sediment	376.1[a]	1.0[a]	1.5[a]	169	2000	Aytas et al., 2012
Nile river, Egypt	Sediment	50.2[a]	0.1[a]	0.2[a]	24.2	29[a]	El-Gamal et al., 2007
Northern Pakistan rivers	Sediment	190.9	0.5[a]	0.7[a]	87.5	920	Qureshi et al., 2014
Ponnaiyar river, India	Sediment	103.8[a]	0.3[a]	0.3[a]	47	60	Ramasamy et al., 2009
Thamirabarani river	Sediment	180	0.5	0.6	85	105	Thangam et al., 2020
Wei river, China	Sediment	134.3	0.36	0.4[a]	64.8	79	Lu et al., 2008
Malaysia (Peninsular)	Soil	208.1[a]	0.6[a]	0.7[a]	92	115[a]	UNSCEAR, 2000

Ulu Tiram, Malaysia	Soil	-	-	-	200	1200	Abdul-Rahman & Ramli, 2007
Xiazhuang, China	Soil	266.0	0.7[a]	1.0[a]	124	152	Yang et al., 2005
World average	Soil	108.7[a]	0.3[a]	0.4[a]	59	70	UNSCEAR, 2000
This Study	Sediment	187.0 – 773.9 (375.1)	0.5 – 2.1 (1.0)	0.6 – 2.8 (1.3)	85.5 – 344.6 (167.6)	104.9 – 422.7 (205.6)	Present work[b]

[a]Calculated by the author using average data given in the reference.
[b]Value in bracket is the average value for all stations.

CONCLUSIONS

This radiological study was carried out to provide information about concentration levels of NORM radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) using gamma ray spectroscopy in surface sediments collected from Juru and Perai river at the Perai Industrial Area. A single ANOVA analysis revealed that there were no significant differences for each of these radionuclides among sediment samples from both rivers. Overall, the main gamma activity arises from ^{40}K which had detected values between 181.8 to 777.3 Bq kg^{-1} with an average of 504.6±59.7 Bq kg^{-1}, ^{232}Th between 69.4 to 312.0 Bq kg^{-1} (average 155.0±12.5 Bq kg^{-1}) and ^{226}Ra values were between 43.4 to 268.0 Bq kg^{-1} (average 114.6±11.4 Bq kg^{-1}). The radioactivities found in this study were higher as compared to most of the studies elsewhere.

Several radiological hazard indices were calculated where the average values of radium equivalent activity (Ra_{eq}) was 375.1 Bq kg^{-1} (range 187.0–773.9 Bq kg^{-1}), and the average values for External (H_{ex}) and Internal (H_{in}) radiation hazard indices was 1.0 (range 0.5–2.1) and 1.3 (range 0.6–2.8), respectively. Both Ra_{eq} and H_{in} were higher than the safety recommended value of 370 Bq kg^{-1} and unity, respectively. Meanwhile, the values of gamma absorbed dose rate (D) in the air were ranged from 85.5 to 344.6 nGy h^{-1} (average 167.6 nGy h^{-1}), which were also higher than the world average values as reported by the UNSCEAR. On the other hand, the estimated annual effective dose (AED) values were found in the range between 104.9–422.7 μSv y^{-1} (average 205.6 μSv y^{-1}), which was below than the 1 mSv y^{-1} (1000 μSv y^{-1}), recommended limit by ICRP for radiological safety of the general public.

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