Global Scientific JOURNALS

GSJ: Volume 8, Issue 11, November 2020, Online: ISSN 2320-9186
www.globalscientificjournal.com

POTENTIAL RADIOLOGICAL SIGNIFICANCE OF NORM IN MARINE SEDIMENTS FROM THE EAST COAST OF PENINSULAR MALAYSIA

Zal U'yun Wan Mahmood, Mohd Zuhair Mohd Sanusi, Yii Mei Wo, Norfaizal Mohamed, Nooradilah Abdullah and Kamarudin Samuding

Radiochemistry and Environment Laboratory, Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia

Correspondence email: zaluyun@nuclearmalaysia.gov.my

ABSTRACT

The NORM radioactivities of ^{238}U, ^{232}Th and ^{40}K in the marine surface sediments collected from 20 sampling points in the east coast of Peninsular Malaysia using a Ponar grab sampler and measured using HPGe gamma-ray spectrometer was studied. The objective of this work is to evaluate the radiological health hazard effect of natural radioactivity associated with sediments at study area. Generally, the mean radium equivalent activity concentration index and other radiological hazard parameter were found to be lower than their maximum permissible limits. The conclusion is made that the sediments in the region confirmed were not posed radiological risks to the public and; sediments are suitable and safe to use in any activities. Furthermore, the results of this study could serve as an important radiometric baseline data upon which future epidemiological studies and environmental monitoring initiatives could be based.

Keywords: Dose**,** marine sediment, Peninsular Malaysia, radiological hazard effect, radionuclides

INTRODUCTION

The radioactivity level of the natural radionuclides such as ^{238}U, ^{232}Th and ^{40}K are termed as background radiation, which will depend on the amount of the radioactive materials in the environment. The background radiation can be high if the environment is polluted either from man-made or natural activities (Chandrasekaran et al., 2014). These radionuclides are widely distributed in the environment as a result of their natural occurrence in the earth's environment or the atmosphere (Botwe et al., 2017). These radionuclides exist with the high radiation levels are due to the presence of large quantities in various geological formations like soils, rocks, plants, sand, sediment, water and air (Singh et al., 2007; SureshGandhi et al., 2014). Although, these radionuclides and their decay products present at trace levels in all ground formations (Tzortzis et al., 2004), however, they constitute an important source of ionising radiation exposure to human and non-human populations (Kam and Bozkurt, 2007; UNSCEAR, 2000).

Since natural radioactivity of these radionuclides has great contributions in ionizing radiations to the world population due to their presence in surrounding such as marine environment compartment includes sediment. Therefore, these radionuclides can be of great concern from the standpoint of radiation protection because of their radio-toxicity. Natural radioactivity in sediment is mainly due to those radionuclides which cause external and internal radiological hazards due to emission of gamma rays and inhalation of radon and its daughters (UNSCEAR, 1988). Measurement of external radiation dose from marine sources is also necessary not only due to its contributions to the collective dose, but also due to variations of the individual dose related to the pathway. These doses strongly depend on the concentrations of ^{238}U, ^{232}Th and their progenies and ^{40}K present in the sediment, which in turns depends upon the geology of the regions (Malik, 2014; Quindos et al., 1994; Radhakrishna et al., 1993).

The ^{40}K activity concentration on average by taking into account the value of the half-lives of ^{238}U (uranium-238; $t_{1/2}$ = 4.5 x10^{9} years), ^{232}Th (thorium-232; $t_{1/2}$ = 1.4 x 10^{10} years), and ^{40}K (K-40; $t_{1/2}$ = 1.3 × 10^{9} years) is about one order of magnitude higher than that of ^{238}U and ^{232}Th (Kovler et al., 2017). Due to such characteristic, thus monitoring the releases main sources of gamma radiation are important to protect the humans (Chandrasekaran et al., 2014) because these radionuclides may cause harmful biological effects such as DNA damage and cancer (Chandrasekaran et al., 2014; Little, 2003; Ravanat et al., 2014; Schmid and Schrader, 2007).

In the recent years, studies on the high background radiation areas in the world have been of prime importance for risk estimation due to long term low-level whole body exposures to the public. Furthermore, since sediment plays a predominant role in aquatic radioecology and plays a role in accumulating and transporting contaminants within the geographic area, thus it is the basic indicator of radiological contamination in the environment (Suresh et al., 2011). Thus, the potential radiological health hazard effects of ^{238}U, ^{232}Th and ^{40}K associated with surface sediments collected at near shore on the east coast of Peninsular Malaysia were studied. This study was conducted as a part of the national project with the title of "Level, trends and effects of natural and anthropogenic radionuclides in the Malaysian marine environment" under IAEA CRP K41017 project: Behaviour and effects of natural and anthropogenic radionuclides in the marine environment and their use as tracers for oceanography studies. The aim of the study is to evaluate the radiological health hazard effect due to natural radioactivity associated with sediments at study area.

MATERIALS AND METHODS

Study area

Our study areas are located along near shore in the east coast of Peninsular Malaysia within latitude in 4.439 – 6.089 ^{o}N and longitude of 102.542 – 103.610 ^{o}E and all points are situated about 9 – 20 km from mainland and water depth ranged from 15.5 – 46.6 m (Table 1). Sediment samples were collected at different 20 points in 2017 – 2018. These sampling points were selected by presuming the mainly sources of natural radionuclides from most of the mainland of the neighbouring countries which are able to accumulate or transfer into Malaysian waters in particular in the east coast of Peninsular Malaysia. The map of the areas for sample collection is shown in Figure 1.

Sample collection and preparation

About one (1) kg of surface sediment samples were collected using a Ponar grab sampler. All the samples were transferred into a zipped plastic bag, stored in cold storage boxes and transported to the laboratory. In the laboratory, the samples were dried at 60^{o}C in an electric oven until a constant weight for 2 – 5 days. All the dried samples were ground into powder form to homogeneity and then, the samples were kept in an airtight container. The ground samples were transferred into 300 mL counting container, sealed and stored for a period in excess of 30 days to establish secular equilibrium between ^{238}U and ^{232}Th and their respective radioactive progenies prior to gamma counting.

Sample counting

All samples were counted for 54000 seconds using High-Purity Germanium (HPGe) gamma-ray spectrometer. Their activity concentrations were corrected to the date of sampling (Noureddine and Baggoura, 1997). Counting times were long enough to ensure a 2σ counting error of less than 10%. The activity concentration of ^{40}K was calculated through its single photopeak at gamma energy line of 1460.7 keV (IAEA, 1989a). Meanwhile, under the assumption that secular equilibrium was reached between ^{238}U and ^{232}Th with their progenies, thus their activity concentrations were calculated through the photopeaks of their progenies. The γ-ray transitions to measure those concentrations of the assigned nuclides in the series are as follows:

(i) ^{226}Ra (186.21 and 241.98 keV), ^{214}Pb (295.21, 351.92 keV) and ^{214}Bi (609.31 keV) for uranium-238 (IAEA, 1989b).

(ii) ^{208}Tl (583.19 keV), ^{212}Pb (238.63 and 300.09 keV) and ^{212}Bi (727.3 keV) for ^{232}Th (Harb et al., 2008).

Table 1: Metadata of sample collection localities, time and water depth

Location	Station ID	Latitude, °N	Longitude, °E	Sampling Date	Water Depth (m)
Melawi	ML01	6.086	102.574	23 Sept. 2017	22.1
Tok Bali	TB 01	5.947	102.542	23 March 2018	15.5
	TB03	5.968	102.594	04 May 2018	23.4
Pulau Perhentian	PP02	5.993	102.754	04 May 2018	35.4
	PP04	5.944	102.631	04 May 2018	25.7
Kuala Terengganu	KT01	5.558	103.148	04 July 2018	30.7
	KT02	5.541	103.220	04 July 2018	42.9
	KT03	5.476	103.298	04 July 2018	46.6
	KT04	5.403	103.340	04 July 2018	44.4
Marang	MG01	5.293	103.378	05 July 2018	42.1
	MG02	5.224	103.408	05 July 2018	44.7
	MG03	5.143	103.445	05 July 2018	41.8
	MG04	5.068	103.480	05 July 2018	41.4
Redang - Bidong	RB01	5.690	103.110	09 Aug. 2018	42.1
	RB03	5.747	102.941	09 Aug. 2018	34.8
Dungun	DG02	4.906	103.554	03 Oct. 2018	44.2
	DG03	4.796	103.610	03 Oct. 2018	40.5
Paka - Kerteh	PK01	4.611	103.626	04 Oct. 2018	39.6
	PK02	4.525	103.655	04 Oct. 2018	39.0
	PK03	4.439	103.632	04 Oct. 2018	37.8

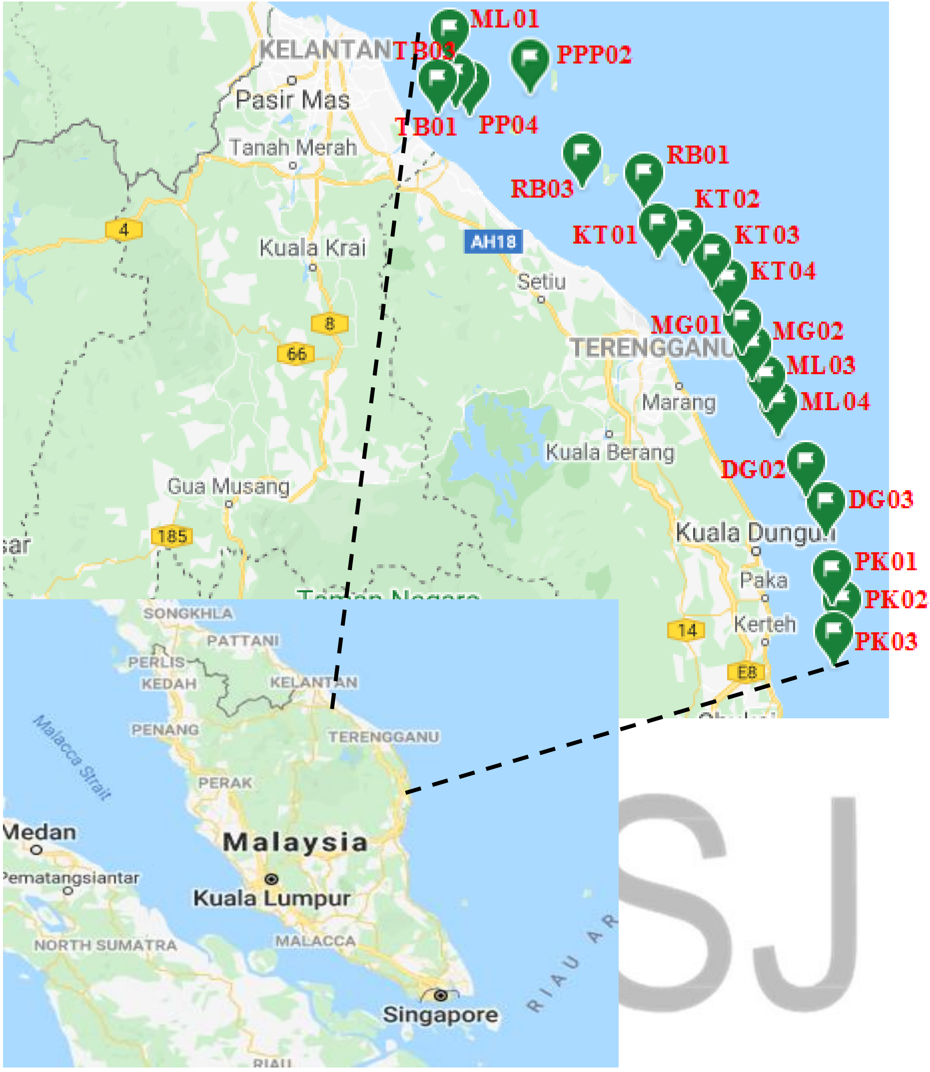

Figure 1: Map shows the points for sediment sampling

The HPGe detector was characterized to provide 25% relative efficiency and 1.8 keV at FWHM for the 1332 keV gamma ray line of ^{60}Co. It was calibrated using a customized gamma multinuclides standard solution which comprise of ^{210}Pb, ^{241}Am, ^{109}Cd, ^{57}Co, ^{123m}Te, ^{51}Cr, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{88}Y and ^{60}Co in the same geometry with the samples. The source used was purchased from Isotope Products Laboratories, USA (source no. 1290-84). IAEA Soil-6 reference material in the same counting geometry was used to check energy and efficiency calibration of the system. The performance of this instrument is monitored regularly to ensure it is fit for purpose (Yii et al., 2009). After considering the volume and the counting time of the sample, the minimum detectable activities (MDA) for thrice radionuclides of ^{238}U, ^{232}Th ^{226}Ra and ^{40}Kwere quantified at 1.0, 1.0 and 5.0 Bq/kg dry weight (dw.), respectively.

RESULTS AND DISCUSSION

Radium equivalent activity concentration index

Due to the non-uniform distributions of radionuclides in sediment, radium equivalent activity concentration index, Ra_{eq} has been defined as a single radiological parameter that compares the specific activity of materials containing varying concentrations of ^{238}U (or^{226}Ra), ^{232}Th and ^{40}K (Berekta and Matthew, 1985). In other word, the Ra_{eq} (Mahur et al., 2008) is a single index or number to describe the radiation output from different mixtures of these radionuclides in sediment samples from different locations and it is related to the external and internal dose due to radon and its daughters. In terms of the radiological health safety assessment, the maximum permissible limit of $Ra_{eq} \leq 370$ Bq/kg had been set of all materials (Berekta and Matthew, 1985; Sivakumar et al., 2014). It was calculated according to equation below:

$$\mathbf{Ra_{eq} = A_U + 1.43A_{Th} + 0.07A_K} \quad (1)$$

Where, A_U, A_{Th} and A_K are the activity concentrations (Bq/kg) for ^{238}U, ^{232}Th and ^{40}K, respectively. It has been assumed here that 370 Bq/kg of ^{238}U or ^{259} Bq/kg of ^{232}Th or 4810 Bq/kg of ^{40}K produces the same radiation dose rate.

The Ra_{eq} values for the sediment samples varied from 23.18 Bq/kg dw. to 138.36 Bq/kg dw.with the mean value of 80.77 Bq/kg dw. (Table 2). However, the calculated values of Ra_{eq} were below the suggested maximal admissible value of 370 Bq/kg at all sampling locations (Beretka and Matthew, 1985). From the radiological protection point of view, the sediments from the east coast of Peninsular Malaysia was not harm to the surrounding people, fisherman, divers or who-else presence in this area and these further confirm that the sediments are suitable to be used in any activities without any restrictions.

Evaluation of radiological hazard effect

i) Absorbed dose rate

The contribution of natural radionuclides to the absorbed dose rates depends on the concentrations of various radionuclides such as ^{238}U (or ^{226}Ra), ^{232}Th and ^{40}K in the sediment (Erenturk et al., 2014). The absorbed dose rates due to radiation of the uniform distribution of these radionuclides from the surface sediment were calculated based on the approach applied from the guidelines provided (UNSCEAR, 2000). The conversion factors used to compute absorbed dose rate (D_{adr}) in sediment per unit activity concentration in Bq/kg dw. corresponds to 0.462 nGy/h for ^{238}U, 0.604 nGy/h for ^{232}Th and 0.042 nGy/h for ^{40}K. Therefore, D_{adr} can be calculated as follows (UNSCEAR, 2000):

$$\mathbf{D_{adr}\ (nGy/h) = 0.462A_U + 0.604A_{Th} + 0.042A_K} \quad (2)$$

Where, A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg dw., respectively.

The absorbed dose rate (D_{adr}) values ranged from 10.20 – 62.45 nGy/h (mean: 36.33 nGy/h) (Table 2). The estimated mean value of D_{adr} contributed from the sediment collected at studied area is lower than the world average absorbed dose rate of 84 nGy/h. This might be due to there were no sources of monazite or minerals which are high content of U and Th deposited as well as no extra source of radiation from man activities that contributed a significant absorbed dose in the studied locations. The results for the relationship of the radionuclides contributed to the dose in the sediments are shown in Table 3. The positive correlation was observed between ^{238}U and ^{232}Th with absorbed dose rate indicated that both radionuclides were mainly contributed to the absorbed dose in the sediment at all studied locations. Hence, this good strong relationship with r = 0.9469 showed that ^{232}Th as a key natural radionuclide played an important role to contribute the emission of radiation in all the studied locations compared to ^{238}U.

ii) Annual effective dose rate

The annual effective dose rate, D_{aedr} (mSv/y) resulting from the absorbed dose values (D_{adr}) was simplified and calculated based on the following equation given by Ravisankar et al. (2012) and UNSCEAR (2000):

$$\mathbf{D_{aedr}\ (mSv/y) = D_{adr}\ nGy/h \times 8760\ h \times 0.7\ Sv/Gy \times 10^{-6}} \qquad (3)$$

The calculated D_{aedr} values were ranged from 0.01 – 0.08 mSv/y with a mean value of 0.05 mSv/y (Table 2), which is slightly lower than the world average value of 0.07 mSv/y . The differences arising from these may be due to the influence of the geo-chemical properties of radionuclides and geological settings of the area, this varies from one place to another and from one locality to another even within the same region (Usikalu et al., 2014). As absorbed dose (D_{adr}), definitely annual effective dose rate by the human beings also due to high concentration of ^{232}Th. This finding is strictly supported by Pearson's correlation coefficient as summarized in Table 3. Furthermore, the finding also indicated that relatively higher concentrations of ^{232}Th (mean value: 37.90 Bq/kg dw.) exist than ^{238}U (mean value: 18.20 Bq/kg dw.) in the sediment. This is could be due to the presence of the input detrital mineral particles associated with sediments at studied locations which have a relatively high concentration of ^{232}Th.

iii) External hazard index

In order to assess the health effects of the radioactivity of the earth's surface materials containing ^{238}U, ^{232}Th and ^{40}K to the people at surrounding marine environment, a single quantity termed as an external hazard index (H_{ex}) should be quantified (SureshGandhi et al., 2014). For the radiation hazard to be negligible and for the purpose of radiological safety precautions, the H_{ex} should be less than unity (1). Radiation hazard index deals with the assessment of excess radiation originating from the sediments at the studied locations were defined as:

$$\mathbf{H_{ex} = (A_U/370\ Bq/kg) + (A_{Th}/259\ Bq/kg) + (A_K/4810\ Bq/kg)} \qquad (4)$$

Where, A_U, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K, respectively. This index value must be less than unity in order to keep the radiation hazard to be insignificant.

GSJ: Volume 8, Issue 11, November 2020
ISSN 2320-9186

Table 2: Radiological hazard parameters of natural radionuclides in surface sediment

Location	Station ID	Activity Concentration (Bq/kg dw.)			Radium Equivalent Activity Concentration Index, Ra_{eq} (Bq/kg dw.)	Absorbed Dose Rate, D_{adr} (nGy/h)	Annual Effective Dose Rate, D_{aedr} (mSv/y)	External Hazard Index, H_{ex}
		^{238}U	^{232}Th	^{40}K				
Melawi	ML01	31.68 ± 3.57	52.59 ± 6.94	162.85 ± 11.17	118.28	53.24	0.07	0.32
Tok Bali	TB 01	32.58 ± 3.70	63.29 ± 8.24	218.25 ± 14.52	138.36	62.45	0.08	0.38
	TB03	21.19 ± 2.98	28.71 ± 3.77	99.18 ± 6.85	69.19	31.30	0.04	0.19
Pulau Perhentian	PP02	18.60 ± 3.75	38.12 ± 5.03	272.08 ± 18.49	92.16	43.05	0.05	0.25
	PP04	32.50 ± 2.66	33.93 ± 4.48	110.59 ± 7.67	88.76	40.15	0.05	0.24
Kuala Terengganu	KT01	24.32 ± 3.24	31.28 ± 4.31	326.76 ± 6.51	91.92	43.85	0.05	0.25
	KT02	17.73 ± 0.48	37.26 ± 4.92	321.97 ± 6.57	93.55	44.22	0.05	0.26
	KT03	16.30 ± 0.52	33.38 ± 4.42	324.53 ± 6.23	86.75	41.32	0.05	0.24
	KT04	9.76 ± 2.05	18.51 ± 2.44	255.30 ± 5.11	54.10	26.41	0.03	0.15
Marang	MG01	3.81 ± 0.29	12.51 ± 1.65	21.10 ± 1.72	23.18	10.20	0.01	0.06
	MG02	16.10 ± 1.19	42.84 ± 5.65	323.15 ± 8.41	99.98	46.89	0.06	0.28
	MG03	11.94 ± 1.39	32.31 ± 4.62	265.00 ± 20.91	76.69	36.16	0.04	0.21
	MG04	12.90 ± 1.72	18.80 ± 2.80	91.52 ± 7.34	46.19	21.16	0.03	0.13
Redang-Bidong	RB01	18.59 ± 3.90	35.25 ± 4.58	425.11 ± 8.33	97.00	46.92	0.06	0.27
	RB03	16.83 ± 3.72	31.91 ± 4.15	322.24 ± 6.86	72.00	34.57	0.04	0.20
Dungun	DG02	14.28 ± 0.39	41.45 ± 5.74	228.22 ± 38.70	89.53	41.22	0.05	0.25
	DG03	10.19 ± 1.31	26.31 ± 3.47	194.32 ± 9.85	61.42	28.76	0.04	0.17
Paka-Kerteh	PK01	4.88 ± 0.36	27.98 ± 3.69	166.67 ± 7.01	56.56	26.15	0.03	0.16
	PK02	22.37 ± 2.87	33.96 ± 4.48	105.59 ± 6.32	78.32	35.28	0.04	0.21
	PK03	15.62 ± 0.45	26.97 ± 3.94	246.67 ± 4.98	71.45	33.87	0.04	0.20

The range calculated external hazard values between 0.06 and 0.38 with a mean value of 0.22 (Table 2). The mean value of the external hazard index of 0.22 at all sampling locations is less than the recommended limit of unity (1). This deterioration values in these locations is due to the lower activity concentration of ^{238}U, ^{232}Th and ^{40}K. This relatively lower contribution to the hazard index due to the ^{238}U is lower followed by the contributions of ^{232}Th and ^{40}K. Furthermore, the less value of H_{ex} due to ^{40}K was not from the same origin source as ^{238}U and ^{232}Th. It has been proven that there is no significant and negative correlation between ^{40}K-^{238}U (r = 0.2298) and ^{40}K-^{232}Th (r = 0.1192). In estimating of H_{ex} found that ^{238}U and ^{232}Th are contributed to the significant value as a result, there has a strong positive correlation with Pearson's correlation coefficient, r = 0.8285 (Figure 2) between both radionuclides in the sediments. This can be implied that very strong relationship shows both ^{238}U and ^{232}Th contributed the emission of significant radiation to all locations.

In the other word, the good strong positive correlation was observed between ^{238}U and ^{232}Th because uranium and thorium come from decay series and occur together in nature (Irena et al., 2012). While, the very weak negative correlation was observed between ^{40}K-^{238}U and ^{40}K-^{232}Th due to ^{40}K origin is a primordial radionuclide and totally was not come from different decay series, which does not undergo any radioactive decay process (Chandrasekaran et al., 2014). This radionuclide was also in accordance with the results (Chen et al., 2001; Elejalde et a., 1996). Therefore, pre conclusion can be made based on our finding that these study areas confirmed not pose radiological risks to the surrounding people, fisherman, divers or who-else presence in this area owing to the harmful effects of ionizing radiation from the natural radionuclides in sediment.

Table 3: Pearson's correlation coefficient (r) for relationship of radiological parameter and radionuclides

Radiological Parameter	**Activity Concentration (Bq/kg dw.)**		
	^{238}U	**^{232}Th**	**^{40}K**
Radium equivalent activity concentration index, Ra_{eq} (Bq/kg dw.)	r = 0.8712 (+ correlation)	r = 0.9678 (+ correlation)	r = 0.0671 (+ correlation)
Absorbed dose rate, D_{adr} (nGy/h)	r = 0.8484 (+ correlation)	r = 0.9469 (+ correlation)	r = 0.1503 (+ correlation)
Annual effective dose rate, D_{aedr} (mSv/y)	r = 0.8484 (+ correlation)	r = 0.9469 (+ correlation)	r = 0.1503 (+ correlation)
External hazard index, H_{ex}	r = 0.8645 (+ correlation)	r = 0.9633 (+ correlation)	r = 0.0894 (+ correlation)

Cluster analysis of dendrogram

Cluster analysis is a method to classify similar observations into a number of clusters based on the observed value of several variables for each individual or average. Each individual within a cluster is same but dissimilar from each other (Sinharay, 2010). Thus, type of hierarchical cluster is a statistical technique for grouping same variable within cluster based on dissimilarities or distance between variable (Yim and Ramdeen, 2015). It can be generated via dendrogram to display the linkage within variable at increasing dissimilarity.

In this study, the averages for 7 parameters i.e. ^{238}U, ^{232}Th, ^{40}K, Ra_{eq}, D_{adr}, D_{aedr} and H_{ex}were classify into three major clusters. Cluster I consisted of ^{238}U, ^{232}Th, D_{adr}, D_{aedr} and H_{ex}; the cluster II set for ^{238}U and Ra_{eq} and cluster III only for single member of ^{40}K. The most significant way to show dissimilarities each average of parameter are by compute square Euclidean distance and the derived dendrogram is shown in Figure 4. This showed the parameter of cluster I was closely distance of result, followed by cluster II. Meanwhile, ^{40}K was identified in cluster III which is far distance result from other parameter. Interpretation from this cluster analysis can be made that D_{adr}, D_{aedr} and H_{ex} are the main contributions hazard effects to the human beings are due to ^{238}U and ^{232}Th present in the study area, while Ra_{ex} due to clearly high concentration of ^{238}U. Generally, ^{40}K found to be higher at study area, rather it was not significant in contributing radiation dose to study area. Therefore, in this current study found that ^{238}U is a key radionuclide has a possibility contributed the radiation dose hazard effect to the study area.

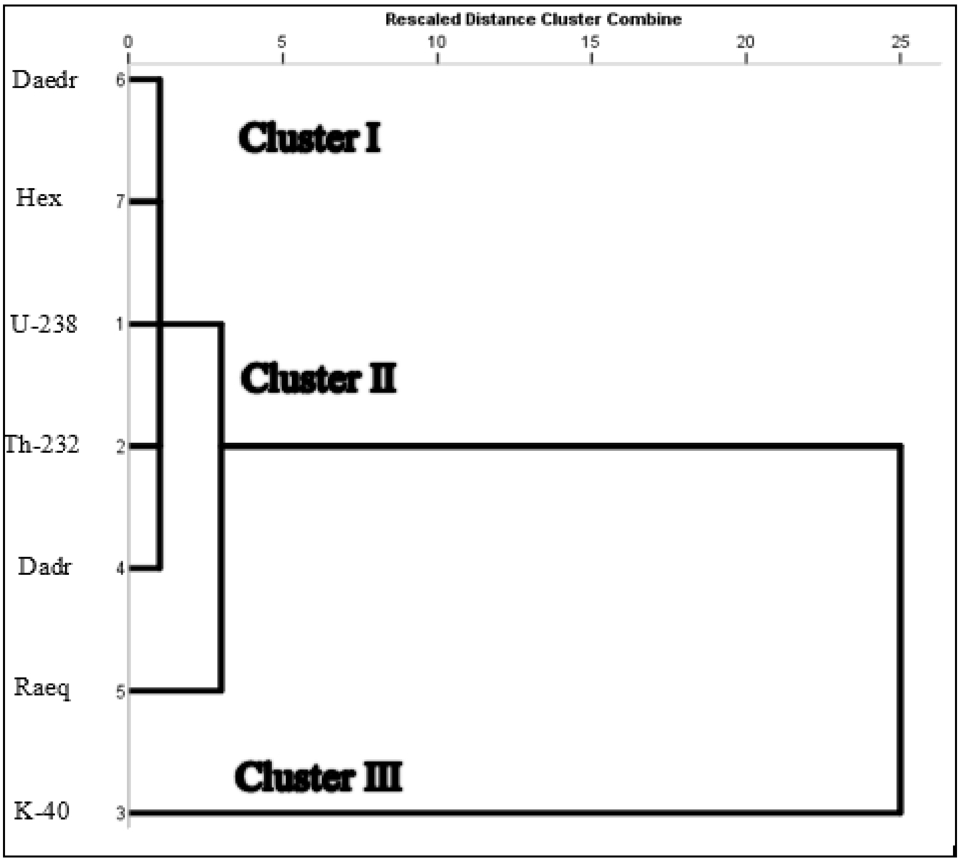

Figure 4: Dendrogram shows the clustering of radionuclides, Ra_{eq} and radiological hazard index

CONCLUSION

The evaluation of radium equivalent activity (R_{aeq}), absorbed dose rate (D_{adr}), annual effective dose rate (D_{aedr}) and external hazard index (H_{ex}) were lower than their maximum permissible limits. This indicates that the potential dose rates to human from the surface sediment radioactivity levels of ^{238}U, ^{232}Th and ^{40}K in the east coast of Peninsular Malaysia have strictly been not present significant risks to human health. Absolutely, it can be confirmed that the surrounding people, fisherman, divers or who-else presence in this area were not posed radiological risks owing to harmful effects of ionizing radiation from the natural radionuclides in sediment. Furthermore, these sediments are suitable and safe to use for any activity purposes.

ACKNOWLEDGEMENT

The authors are highly appreciated and thankful to IAEA for granting the budget to implement this project. Thanks also to all project and laboratory members; and boatmen for their constant assistant throughout the period of work. Lastly, the authors are highly indebted to our top management for their constant support and encouragements in each and every stage of the manuscript preparation.

REFERENCES

Beretka, J. and Matthew, P.J. (1985). Natural radioactivity of Australian building materials. industrial wastes and by-products. Health Physics, 48: 87-95.

Botwe, B.O., Schirone, A., Delbono, I., Barsanti, M., Delfanti, R., Kelderman, P., Nyarko, E., and Lens, P.N.L. (2017). Radioactivity concentrations and their radiological significance in sediments of the Tema Harbour (Greater Accra, Ghana). Journal of Radiation Research and Applied Sciences, 10: 63-71.

Chandrasekaran, A., Ravisankar, R., Senthilkumar, G., Thillaivelavan, K., Dhinakaran, B., Vijayagopal, P., Bramha, S.N. and Venkatraman, B. (2014). Spatial distribution and lifetime cancer risk due to gamma radioactivity in Yelagiri Hills, Tamilnadu, India. Egyptian Journal of Basic and Applied Sciences, 1: 38-48.

Chen, C.J., Huang, C.C. and Yeh, C.H. (2001). Introduction to natural back-ground radiation in Taiwan. Physic Bi-Monthly, 23(3): 44-443.

Elejalde, V., Herranz, M., Romer, F. and Legarda, E. (1996). Correlations between soil parameters and radionuclide contents in samples from Biscay (Spain). Water Air Soil Pollution, 89: 23-31.

Erenturk, S., Yusan, S., Alkim Turkozu, D., Camtakan, Z., Kirami Olgen, M., Aslani, M.A. A., Aytas, S., and Akif Isik, M. (2014). Spatial distribution and risk assessment of radioactivity and heavy metal concentrations of sediment, surface water and fish samples from Lake Van, Turkey. Journal of Radioanalytical and Nuclear Chemistry, 300: 919-931.

Harb, S., El-Kamel A.H., Abd El-Mageed, A.I., Abbady, A., and Wafaa Rashed (2008). Concentration of U-238, U-235, Ra-226, Th-232 and K-40 for some granite samples in eastern desert of Egypt. Proceedings of the 3rd Environmental Physics Conference, 19-23 Feb. 2008, Aswan, Egypt.

IAEA (1989a). Construction and use of calibration facilities for radiometric field equipment. Technical Report Series No. 309, IAEA, Vienna.

IAEA (1989b). Measurement of radionuclides in food and the environment - A guidebook. Technical Reports Series No. 2 9 5, IAEA, Vienna, pp 1-170.

Irena, T., Dusan, G. and Nada, M. (2012). Multivariate statistical analysis of hydrochemical and radiological data of Serbian spa waters. Journal of Geochemica Exploration, 112: 226-234.

Kam, E., and Bozkurt, A. (2007). Environmental radioactivity measurements in Kastamonu region of northern Turkey. Applied Radiation and Isotopes, 65(4), 440-444.

Kovler, K., Friedmann, H., Michalik, B., Schoeyers, W., Tsapalov, A., Antropov, S., Bituh, T., and Nicolaides, D. (2017). Basic aspects of natural radioactivity. In: Naturally occurring radioactive materials in construction, Schroeyers, W. (ed). Elsevier, United Kingdom, p: 13-35.

Little, M. (2003). Risks associated with ionizing radiation Environmental pollution and health. British Medical Bulletin, 68(1): 259-275.

Mahur, A.K., Kumar, R., Sonkawade, R.G., Sengupta, D., and Prasad, R. (2008). Measurement of natural radioactivity and radon exhalation rate from rock samples of Jaduguda uranium mines and its radiological implications. Nuclear Instruments and Methods in Physics Research Section B, 266: 1591-1597.

Malik, F. (2014). Natural radioactivity in sand samples collected along the bank of river Indus in the area spanning over Gilgit to Lowarian, Pakistan: Assessment of its radiological hazards. Journal of Radioanalytical and nuclear Chemistry, 299(1): 373-379.

Noureddine, A. and Baggoura, B. (1997). Plutonium isotopes, 137Cs, 90Sr and natural radioactivity in marine sediments from Ghazaouet (Algeria). Journal of Environmental Radioactivity, 34(2), 127-138.

Quindos, L., Fernandez, P., Soto, J., Rodenas, C., and Gomez, J. (1994). Natural radioactivity in Spanish soils. Health Physics, 66(2): 194-200.

Radhakrishna, A., Somashekarappa, H., Narayana, Y., and Siddappa, K. (1993). A new natural background radiation area on the southwest coast of India. Health Physics, 65(4): 390-395.

Ravanat, J., Breton, J., Douki, T., Gasparutto, D., Grand, A., Rachidi, W. and Sauvaigo, S. (2014). Radiation-mediated formation of complex damage to DNA: A chemical aspect overview. The British Journal of Radiology, 87(1035): 20130715-1-20130715-6.

Ravisankar, R., Vanasundari, K., Chandrasekaran, A., Rajalak-shmi, A., Suganya, M., Vijayagopal, P. and Meenakshisundram, V. (2012). Measurement of natural radioactivity in building materials of Namakkal, Tamilnadu, India using gamma-ray spectrometry. Applied Radioactivity Isotope, 70: 699-704.

Schmid, E. and Schrader, T. (2007). Different biological effectiveness of ionising and non-ionising radiations in mammalian cells. Advances in Radio Science, 5(1): 1-4.

Sinharay, S. (2010. An overview of statistics in education. International Encyclopedia of Education (Third Edition), 1-11.

Singh, H.N., Shanker, D., Neelakandan, V.N. and Singh, V.P. (2007). Distribution patterns of natural radioactivity and delineation of anomalous radioactive zones using in situ radiation observations in Southern Tamil Nadu, India. Journal of Hazardous Materials, 141(1): 264-272.

Sivakumar, S., Chandrasekaran, A., Ravisankar, R., Ravikumar, S.M., Prince Prakash Jebakumar, J., Vijayagopal, P., Vijayalakshmi, I. and Jose, M.T. (2014). Measurements of natural radioactivity and evaluation of radiation hazards in coastal sediments of east coast of Tamilnadu, India using statistical approach. Journal of Taibah University for Science, 8: 375-384.

Suresh, G., Ramasamy, V., Meenakshisundaram, V., Venkatachalapathy, R., and Ponnusamy, V. (2011). Influence of mineralogical and heavy metal composition on natural radionuclide concentrations in the river sediments. Applied Radiation and Isotopes, 69: 1466-1474.

SureshGandhi, M., Ravisankar, R., Rajalakshmi, A., Sivakumar, S., Chandrasekaran, A. and Pream Anand, D. (2014). Measurements of natural gamma radiation in beach sediments of north east coast of Tamilnadu, India by gamma ray spectrometry with multivariate statistical approach. Journal of Radiation Research and Applied Sciences, 7(1):7-17.

Tzortzis, M., Svoukis, E. and Tsertos, H. (2004). A comprehensive study of natural gammaradioactivity levels and associated dose rates from surface soils in Cyprus. Radiation Protection Dosimetry, 109 (3): 217-224.

UNSCEAR (1988). Report to the general assembly scientific annexes. New York: United Nations.

UNSCEAR (2000). Exposure from natural radiation sources, Annex-B. Sources and effects of ionizing radiation. United Nations, New York: United Nations Scientific Committee on the Effects of Atomic Radiation.

Usikalu, M.R., Akinyemi, M.L. and Achuka, J.A. (2014). Investigation of radiation concentrations in soil samples collected from selected locations in Ogun State, Nigeria. 2014 International Conference on Environment Systems Science and Engineering, IERI Procedia, 9: 156-161.

Yii, M.-W., Zaharudin, A., Abdul-Kadir, I. (2009). Distribution of naturally occurring radionuclides activity concentration in the East Malaysian marine sediment. Applied Radiation and Isotopes, 67(4): 630-635.

Yim, O. and Ramdeen, K.T. (2015). Hierarchical cluster analysis: Comparison of three linkage measures and application to psychological data. The Quantitative Methods for Psychology, 11(1): 8-21.