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Radioactivity and Hazard Risk Analysis of Soil Samples Taken from Former Mining Area in Klang Valley

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ABSTRACT

Radioecology is considered as a significant field in environmental radioactivity that observe the impact of natural or man-made radiation to human population. The awareness towards risk from the radioactivity of the former mining area on human health is always lacking and often underestimated. Hence, this study aimed to evaluate the radioactivity from the residential area in Klang Valley which was a former mining area and to determine its associated risk. 20 soil samples have been collected systematically and analyzed by using the High Purity Germanium (HPGe) gamma spectrometer (Canberra, Australia). The ^{226}Ra, ^{232}Th and ^{40}K were predetermined from the soil samples and were ranged from 11.91-54.09 Bq/kg, 8.95-49.50 Bq/kg and 974.64 Bq/kg, respectively. The risk of radiation hazard to human being were analyzed and categorized based on studied area. As per analyzed the radium equivalent activity, radiation hazard index, external hazard index and total air absorbed dose rate, the value were 305.90 ± 111.84 Bq/kg, 2.25 ± 0.85, 0.30 ± 0.84 and 139.5 ± 49.42 nGy/h, respectively. These values were compared with the recommendation by United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR) international standard safe limit. Locations at point P2, P6, P16 and P17 were observed to have highest potential risk and has a radioactive element that can endanger the health of the surrounding population on external exposure via external exposure and ingestion from the food chain. Overall, the mean annual effective dose from the external exposure received by an individual was estimated to be 0.17±0.01 mSv/y, which is far below than the annual dose limit of 1 mSv/y of the public.

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1. Introduction

Human beings are constantly exposed to radiation including from terrestrial natural radionuclides in water, air, soil and plants and artificial radioactivity from fallout in nuclear testing or from extra-terrestrial such as cosmic ray. Usually, the external exposure attributes from soils, ore and cosmic rays while internal exposure obtained from inhalation and ingestion through nourishments or from drinking water [1] 80% of doses contribution in the environment are obtained from the natural radionuclides while the remaining 20% is from cosmic ray and nuclear processes [2]. Potassium (^{40}K), uranium (^{238}U), thorium (^{226}Th) and the radioactive gas radon are the main naturally occurring radioisotopes that are found in terrestrial environment. Radon comes from the ground as a result of the direct decay of naturally occurring radium and is a major source of radiation exposure [3]. Radioactivity level in the earth's environment is basically dependent on the geological, geographical conditions, and the type of soils. Humans has increasingly been exposed to this ionizing radiation that occurs naturally on the earth which makes it unavoidable to human health. The event of natural radiation exposures has been credited to certain contributors particularly. It is inevitable that the effect of radionuclides in the environment especially in soil has become increasingly important for the mankind [4-7].

There are number of evidence that relates the environmental issues with the Naturally Occurring Radioactive Materials (NORM) particularly in solid minerals mines. These problems can be happened due to the process of drilling, leaching, handling, storage, transportation of mineral ores and the use of contaminated equipment or waste media without controls. Previous studies have been demonstrated that there is significant finding that radioactivity concentration from former tin mining area is higher when compared to mining area [8]. These usually could lead to the spread of NORM contaminating the environment, resulting in potential radiation exposure of members of the public. Due to the health risks associated with the exposure to NORM and inhalation of the short-lived decay products of radon, international bodies and governmental organization such as International Commission on Radiological Protection (ICRP) and Environmental Protection Agency (EPA) have adopted strong measures at minimizing such exposure [9,10]. Radiological impact from mining activities is practically not regulated under radiation licensing authority and so there is generally lack of awareness and knowledge on the radiological hazards and exposure levels to NORMs in mining areas.

Previous studies have shown that radiation risks resulting from the specific radioactivity of these concern radionuclides, especially from the soil in the former mining area, such as ^{238}U, ^{239}Th and ^{40}K [11-14]. The concentrations of ^{226}Ra, ^{228}Ra and ^{40}K on terrestrial especially in the areas of Peninsular Malaysia had been widely described but to the best of our knowledge, none has reported about the radiogenic risk of former mining area. Hence, the study herein is restricted to the former mining area which has become residential area. Briefly, Klang Valley is an area in central Selangor, which centred in Kuala Lumpur. The area has become a primary industrial and commercial sector, bordered to the north and east by the Titiwangsa mountain and to the west by the Strait of Malacca. During the colonization of British in year 1826 to 1957 in Tanah Melayu now known as Malaysia, Kuala Lumpur or part of the Klang Valley was a main location for tin mining activities with coverage area of 11,773 ha [15]. Tin ore is considered as radioactive material with a high content of monazite and zircon. Uranium and thorium concentrate during the tin ore processing procedures and are responsible for the high amounts of uranium and thorium found in the tailing dump and contaminated soil samples [16].

Therefore, present study focuses on measurement of natural radioactivity concentration in the soil of former mining area in Klang Valley residence area, and to evaluate the radiation exposure as

well as radiation hazard to the population living in the area. These measurements also will benefit the authorities to classify and establish the present state of the environment in this area.

2. Methodology

2.1 Sampling Sites

In this study, the soil samples were primarily collected near to Taman Medan, Petaling Jaya one of biggest residential area in Klang Valley (with ~25,000 populations in year 2020). 20-point locations had been randomly chosen during the sampling collection. Several precautions were considering during the sample collections including the soil should be moderately to properly permeable, minimum amount of earthworm and rodent activity may affect the soil mixture. These samples were collected with a shovel to a depth of 5 cm with a total surface area of at least 200 cm^2 and composed to create a collection of a single labelled sample. Approximately, around 1 kg of soil samples were collected and placed in the labelled High-Density Polyethylene (HDPE) bag. All the samples were screened first before it was taken to the laboratory. All the sampling sites was labelled with simple coding name and GPS coordinates as tabulated in Table 1 and illustrated in map Figure 1.

Table 1
Summary of the sampling locations and description of the soil samples

Sample Code	Present location to residential area	Soils Colour	Coordinates
P1	within 100m	Greyish Black	3.081899, 101.633806
P2	within 100m	Greyish Brown	3.081608, 101.634106
P3	within 100m	Brown, orange	3.079529, 101.637221
P4	>100 m	Black, orange	3.078636, 101.637426
P5	>100 m	Greyish Brown	3.076975, 101.635343
P6	within 100m	Greyish Brown	3.077281, 101.635073
P7	within 100m	Greyish Brown	3.075685, 101.633506
P8	within 100m	Grey	3.076108, 101.633991
P9	within 100m	Black	3.075746, 101.637638
P10	>100 m	Black, orange	3.074757, 101.640301
P11	within 100m	Brown, orange	3.072843, 101.638602
P12	>100 m	Greyish Black	3.071006, 101.639316
P13	>100 m	Light Grey	3.071273, 101.640014
P14	within 100m	Grey	3.072693, 101.639642
P15	>100 m	Light Grey	3.071247, 101.637305
P16	>100 m	Greyish Black	3.071103, 101.636350
P17	within 100m	Black, orange	3.070964, 101.632927
P18	>100 m	Light Grey	3.071211, 101.630312
P19	>100 m	Greyish Brown	3.078242, 101.626291
P20	>100 m	Greyish Black	3.078934, 101.625056

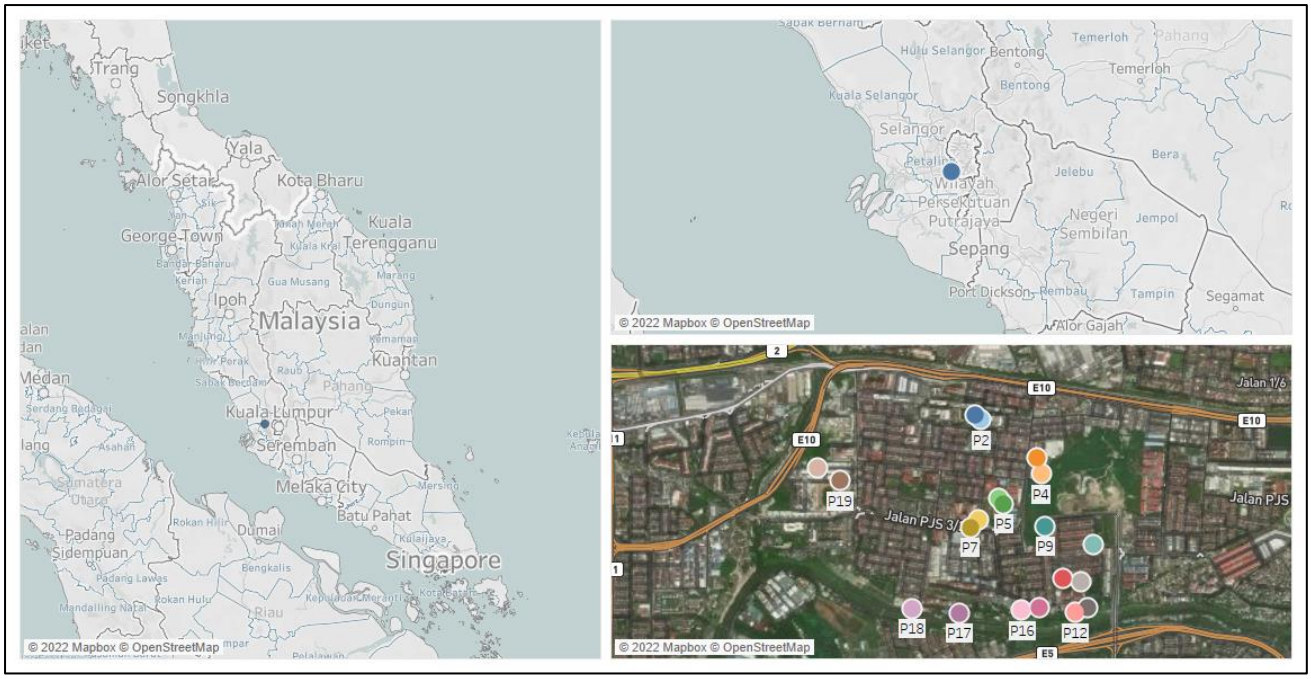

Fig. 1. Visualized map of sampling locations in Taman Medan, Kuala Lumpur

2.2 Samples Preparation

Briefly, the collected soil samples were spread on a clean tray and allowed to dry at room temperature for several days. Then, the samples were stored in drying cabinet with temperature of 50°C with a slow airflow which help to accelerate the drying process without loss of radionuclides from the samples. Low carbon nickel trays are used for the sampling of all the soil. Trays are cleaned easily with detergents or mineral acids (usually HCl). If the sample is not completely dry in the beginning, an initial drying step should be introduced at 105 °C. The drying time for these samples of soils was taken three days. The collected samples were dried in an oven at a temperature of 105 °C overnight in order to remove any available moisture.

After drying, the samples were crushed and screened with a mesh with holes of 0.2 mm in diameter to remove organic materials, stones, gravel and lumps. The homogenized soil should normally have a mesh size of 2 mm. The homogenized samples were then weighed and a mass of 200 g of each sample was packed in a plastic cylindrical container with a height of 7 cm and a diameter of 6 cm. For 30 days, the plastic containers were sealed with adhesive tape so that ^{238}U and its short-lived progenies could achieve a secular radioactive balance before the gamma counting measurement.

2.3 Gamma-Ray Spectrometer Measurements

The gamma ray spectrometry analysis was carried out at Malaysia Nuclear Agency, Malaysia. The detector used in this measurement were High purity Germanium (HpGe) (Canberra model GC2018, Australia) which integrate with the Genie-2000 software for the read-out purpose. The HPGe consists of a detector with a relative efficiency of 20% with a resolution of 1.8 keV for 1332 keV gamma ray emissions of ^{60}C. In order to reduce current leakage and thermal noise, liquid nitrogen cooled the gamma detector at 77 K and the warm-up sensor was coupled with high voltage detector bias supply. The preamplifier was placed inside a lead shield to reduce radiation in the background. For each

radionuclide, the minimum detectable activity (MDA) is set for ^{238}U, ^{232}Th and ^{40}K at 1 Bq/kg, 2 Bq/kg and 13 Bq/kg, respectively.

All samples were counted for 50,000 seconds using spectrometer and corrected for density and sampling date. A container of the same geometry filled with inert material counted was used to determine the background counts. Counting times were long enough to ensure a 2σ counting error of less than 10%. Previous studies reveal that minimum counting time of 10 hours (36,000 seconds) is sufficient to provide adequate counts under the various gamma-ray peaks [17,21]. The concentrations of ^{226}Ra and ^{232}Th were calculated from the weighted mean activity values determined for various emissions. The ^{226}Ra, ^{238}U and ^{232}Th were measured through the gamma transitions of their progenies; ^{214}Pb (295.21 and 351.92 keV) and ^{214}Bi (609.31 keV, 1120.29 keV and 1764.49 keV) were used for determination of ^{226}Ra. ^{238}U activity was obtained through the emissions at the energy lines of 351.92 keV (^{214}Pb) and 609.31 keV, 768.36 keV, 1120.29 keV, 1238.11 keV and 1764.49 keV (all of ^{214}Bi). The energy lines of 238.63 keV (^{212}Pb), 338.4 keV, 911.07 keV, 969.11 keV (^{228}Ac) and 583.19 keV (^{208}Tl) were used to calculate the activity for ^{232}Th. Meanwhile, ^{40}K content was measured directly via its 1460.7 keV energy peak.

2.4 Radiological Hazard and Radiogenic Risk

In this study, the radiological hazard can be determined by the calculation of activity concentration and radium equivalent of radionuclides. This activity index provides a useful guidance for the regulation of radiation protection safety standards for the general public living in common residence [7]. Since the peak of the gamma spectrum with the count rate R_n are obtained, the mean activity concentration of nuclide, n can be calculated (Bq/kg) [2].

$$R_n = R_T - R_b \tag{1}$$

where R_T is the gross count rate of nuclide, n (count/s) and R_b is the background count rate, n (count/s). Once R_n is calculated, the activity concentration of radionuclide, A_n can be determined using equation below

$$A_n = \frac{R_n}{\epsilon m P_\gamma} \tag{2}$$

where A_n is the concentration of radionuclide activity in the sample given in Bq/kg, R_n is the net count rate below the corresponding peak, P_γ is the intensity of the radionuclide, m is the sample mass in gram and ϵ is the detector efficiency [2]. Subsequently, the radium equivalent activity, Ra_{eq} were evaluated as a weighted sum of activities of the ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K radionuclides based on the assumption that ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K produce the same gamma ray dose rate. The Ra_{eq} as suggested can be calculated from the following relationship

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \tag{3}$$

where, A_{Ra}, A_{Th}, and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively. To be non-hazardous, the calculated Ra_{eq} should not exceed a maximum value of 370 Bq/kg [18]. Another alternative for Ra_{eq} called the representative level index, $I_{\gamma r}$, is defined as the following formula

$$I_{\gamma r} = \frac{1}{150Bq/kg}A_{Ra} + \frac{1}{100Bq/kg}A_{Th} + \frac{1}{1500Bq/kg}A_K \tag{4}$$

The radium equivalent activity *(Ra_{eq})*, external hazard index (H_{ex}), and total air absorbed dose rate at 1 m above ground of the present work and annual effective dose, had been calculated from the mean NORM activity at each location. External hazard index, H_{ex} is another parameter that enables us to evaluate the additional radiological hazard of natural gamma-radiation to the people exposed to the radiation daily. The formalism of H_{ex} as below

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

where Q_U, Q_{Th} and Q_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K, respectively. This equation was derived from the measured concentration of radionuclides in environmental materials to calculate the absorbed dose rate in air at 1.0 m above ground. The total air absorbed dose rate, *D* (nGy/h) due to the mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg can be calculated using the formula given by [19].

$$D\ (\mathrm{nGy/h}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (6)$$

In order to estimate the annual effective dose, the conversion factor, *Q* of 0.7 Sv/Gy from the absorbed dose in air to effective dose. It was also assumed that the people spent almost 20% of their time outdoor occupancy factor, O_f [20].

$$AED = D \times T \times Q \times Q_f \times 10^{-6} \quad (7)$$

where *AED* is the annual effective dose rate in mSv/yr, *T* is time in hours in 1 year which is 8760 hours and *D* is the air absorbed dose rate in nGy/h.

2.5 Statistical Analysis

Statistical Packages for the Social Sciences (SPSS) version 25.0 was used for statistical analysis. In this study, the Shapiro Wilk-Distribution were used to test the normality of the activity concentration of radionuclides. The differences between 20 locations of sampling sites were analyzed by using ANOVA analysis ($p < 0.05$) to determine whether the activity concentration of radionuclides was statistically significant or insignificant. The quantitative variables were expressed as mean ± standard deviation.

3. Results and Discussion

3.1 Activity Concentration

We successfully analyzed and evaluate the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in 20 soil samples using HPGe gamma detector. The Ra_{eq}, I_{yr}, H_{ex}, nGy/h and annual effective dose (mSv/yr) were also measured and analyzed separately. Table 2 tabulate the descriptive statistics of radioactivity concentration and radiological hazard based on the mean and standard deviation value. Figure 2 illustrate the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K for former mining area soils in the sampling sites. The activity concentrations for ^{226}Ra and ^{232}Th were ranged from 11.9-54.1 Bq/kg (mean 122.7±5.9 Bq/kg) and 8.9-49.5 Bq/kg (mean 107.5±4.3 Bq/kg), respectively.

Table 2
The mean radioactivity of ^{226}Ra, ^{232}Th and ^{40}K and their respective hazard metrics in all sampling sites

Soil Samples	Mean radioactivity (Bq/kg)			Hazard metrics				
	^{226}Ra	^{232}Th	^{40}K	Ra_{eq} (Bq/kg)	$I_{\gamma r}$	H_{ex}	D (nGy/h)	AED (mSv/y)
P1	107.7 ± 14.6	121.0±11.9	337.8 ± 28.3	306.7 ± 51.6	2.15±0.39	0.84±0.15	139.1±26.7	0.17±0.03
P2	175.2 ± 23.5	241.5 ± 23.8	102.1 ± 9.4	528.4±77.5	3.65±0.57	1.43±0.24	232.0±41.8	0.28±0.05
P3	157.6 ± 18.6	81.3 ± 7.2	745.5 ± 61.7	331.3±48.9	2.36±0.37	0.91±0.15	154.7±27.5	0.19±0.03
P4	94.9 ± 12.1	139.4 ± 12.3	315.2 ± 26.6	317.6±49.7	2.24±0.38	0.87±0.15	142.3±27.0	0.17±0.03
P5	64.2 ± 8.8	74.02 ± 7.94	164.9 ± 14.1	171.3±40.1	1.18±0.31	0.47±0.12	76.1±21.0	0.093±0.03
P6	235.5 ± 19.0	223.8 ± 16.0	100.3 ± 86.4	563.3±61.9	3.88±0.46	1.50±0.17	244.3±28.8	0.30±0.04
P7	174.7 ± 21.9	75.5 ± 9.8	495.4 ± 41.3	320.1±55.9	2.56±0.42	0.89±0.16	151.7±27.8	0.19±0.03
P8	167.3 ± 21.6	97.4 ± 11.4	623.7 ± 51.9	354.6±58.0	2.52±0.43	0.98±0.17	165.1±30.1	0.20±0.04
P9	135.8 ± 21.0	84.9 ± 11.0	703.9 ± 58.7	311.4± 56.8	2.22±0.42	0.86±0.16	146.4±28.6	0.18±0.04
P10	94.9 ± 11.8	70.8 ± 5.6	437.4 ± 36.5	229.8± 39.8	1.63±0.31	0.64±0.11	107.5±19.9	0.13±0.03
P11	86.0 ± 11.6	166.2 ± 15.4	135.2 ± 11.9	334.1±53.6	2.33±0.32	0.90±0.16	146.0±28.7	0.18±0.04
P12	32.8 ± 5.2	75.5 ± 7.7	264.1 ± 22.4	161.1±36.2	1.15±0.29	0.44±0.10	71.8±18.9	0.088±0.02
P13	92.4±10.8	81.6±8.1	341.5±28.5	235.4±42.4	1.66±0.33	0.64±0.13	107.3±22.8	0.13±0.03
P14	87.0 ± 11.3	91.6 ± 10.0	117.4 ± 10.3	227.2± 45.6	1.58±0.35	0.62±0.14	101.3±24.4	0.13±0.03
P15	137.6 ± 18.2	84.5 ± 8.3	568.7 ± 47.3	302.3± 50.0	2.14±0.38	0.84±0.14	141.4±25.4	0.17±0.03
P16	177.9 ± 23.4	84.4 ± 9.4	991.0 ± 81.9	374.9±56.9	2.69±0.42	1.04±0.16	178.7±28.9	0.22±0.04
P17	180.6 ± 24.3	135.3 ± 13.5	606.7 ± 51.0	420.9±63.6	2.96±0.47	1.16±0.18	194.6±32.1	0.24±0.04
P18	50.8 ± 5.9	31.1± 3.7	146.7 ± 12.5	106.6±31.3	0.75±0.25	0.29±0.091	48.9±16.9	0.06±0.02
P19	103.2 ± 13.8	84.2 ± 8.5	347.7 ± 29.1	250.4±45.9	1.76±0.35	0.69±0.13	115.4±23.5	0.14±0.03
P20	97.7 ± 12.7	107.2 ± 12.0	290.8 ± 24.0	273.4±49.8	1.92±0.38	0.75±0.15	123.9±26.0	0.15±0.03

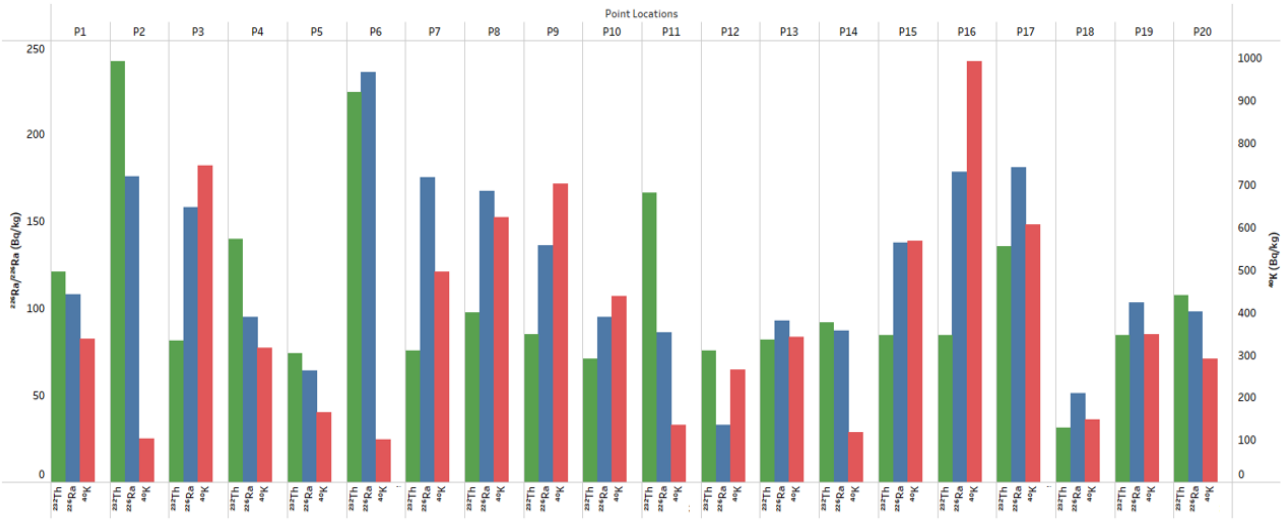

Fig. 2. Figure 2 shows distribution of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples

Furthermore, the activity concentrations of ^{40}K from all sampling sites were ranged from 100.2 - 703.9 Bq/kg (384.3±259.0 Bq/kg). As observed from Table 2, the highest mean activity concentrations of ^{226}Ra and ^{232}Th were 235.5±19.0 Bq/kg at sampling site P6 and 241.5±23.8 Bq/kg at sampling site P2, respectively. Meanwhile, the highest mean activity concentrations of ^{40}K were 991.0±259.0 Bq/kg at sampling site P16. Hence, the concentrations were varied along with the locations of the samples probably due to difference concentration of rare-earth materials.

As tabulate in Table 3, the worldwide average concentrations according to UNSCEAR for ^{226}Ra and ^{232}Th were 32 and 45 Bq/kg, respectively.

Table 3
Comparison of previous studies and present research on activity concentration of ^{226}Ra, ^{232}Th and ^{40}K

Location	Level	Activity concentration (Bq/kg)			
		^{226}Ra	^{232}Th	^{40}K	^{238}U
Malaysia (UNSCEAR, 2000)	Minimum	41	105	75	-
	Maximum	94	110	430	86
	Average	67	82	310	66
Peninsular Malaysia [22]	Minimum	38	63	17	49
	Average	74	-	-	-
World Average (UNSCEAR, 2000)	Average	32	45	420	-
Present study	Minimum	32.8±5.2	31.1± 3.7	100.3 ± 86.4	NA
	Maximum	235.5±19.0	241.5 ± 23.8	745.5 ± 61.7	
	Average	122.7±5.9	107.5±4.3	391.7±36.7	

3.2 Radiological Hazard

Radiological hazard from the activity of ^{226}Ra, ^{232}Th and ^{40}K were estimated by calculating the related risk parametric such as radium equivalent activity, Ra_{eq} and radiation hazard index. Table 2 also shows the distribution of Ra_{eq} in soils of former mining area in all sampling sites and were ranged from 106.6 to 563.3 Bq/kg (305.9±111.8 Bq/kg). Notably, the Ra_{eq} in P2, P6, P16 and P7 were exceed the recommendation limit. Furthermore, to estimate the level of gamma radiation hazard associated with natural gamma emitters in the soil we utilize the representative index or radiation hazard index, I_{ex}. In the present study, the I_{ex} were ranged from 0.75 - 3.88 with mean value of 2.09±0.75. This index

is 28% higher than the hazard index for soil in Peninsular Malaysia [21]. Notably, only soil from sampling sites of P5 and P12 having values less than the background level.

Figure 3 present the radiation hazard index and external hazard index of the sampling sites.

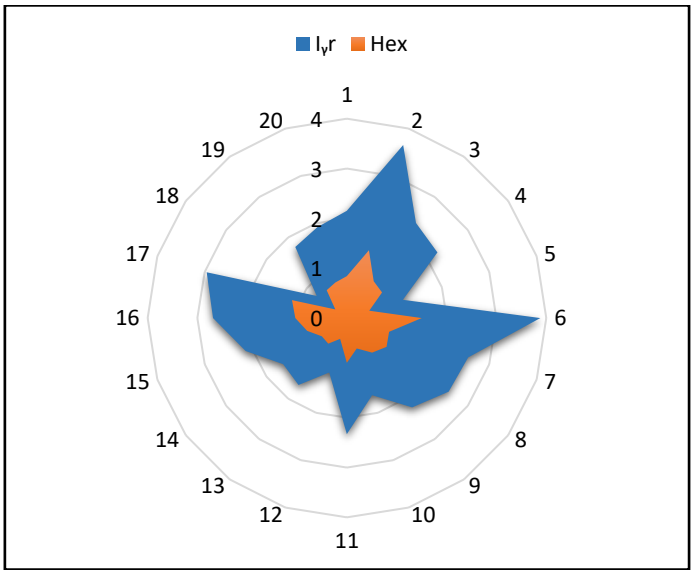

Fig. 3. Illustrates the index of radiation hazard and external hazard in soil samples for 20 separate locations

In addition, the external hazard index, H_{ex} indicate the radiation hazard from the emission of gamma rays due to the present of NORM radionuclides. As observed, the H_{ex} values were ranged from 0.29 to 1.50, with a total mean value of 0.84±0.30. External hazard index at P2, P6, P16 and P17 were above the recommended value of 1, which indicates that there was significant hazard at the respective sampling sites, and this can be seen on Figure 3. Based on Table 2, the total air dose rate for all soil samples were ranged from 48.95 to 244.36 nGy/hr with the mean absorbed dose rate of 139.40±49.42 nGy/hr. This value was higher than the estimated average global terrestrial radiation of 57 nGy/hr which range from 18 to 83 nGy/hr. However, according to UNSCEAR report, the absorbed dose rate of soil in Peninsular Malaysia is 92 nGy/hr with range from 55-130 nGy/hr and in Thailand, the mean absorbed dose rate is 77 nGy/hr with 100 nGy/hr were recorded as the highest value [24].

Figure 4 shows the relative contributions of ^{226}Ra, ^{232}Th and ^{40}K to all activity concentrations from the sampling sites. The average relative contributions to activity concentrations due to ^{226}Ra, ^{232}Th and ^{40}K are 22, 21 and 57%, respectively. The average relative contributions of ^{40}K gives the highest percentage out of the other radionuclides. Hence, ^{40}K exists as natural radionuclide in soil and thus, it has highest amount of potassium composition in soil.

Table 4 compares the reported values of radium equivalent activity, radiation hazard index, external hazard index and total air absorbed dose rate obtained in other countries' published data with the current estimation. The effective dose received by an individual staying around Taman Medan of Klang Valley area might be expected from the terrestrial natural gamma radiation was from 0.06 to 0.30 mSv/yr with mean annual effective dose at 0.17±0.01 mSv/yr. This value was far below than the annual dose limit of 1 mSv/yr for the general public by a factor 5.9.

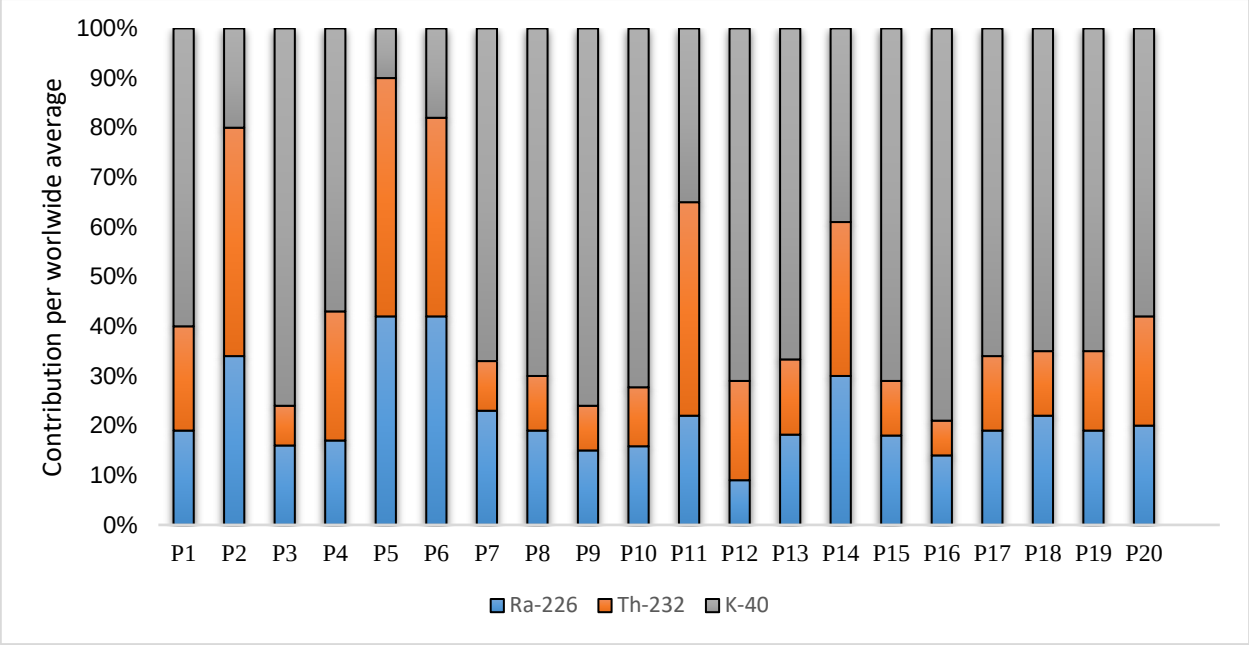

Fig. 4. Figure 4 depicts the relative distribution of each radionuclide from the sampling sites

Table 4
The comparison of radium equivalent activity, representative level index, external hazard index and total air absorbed dose rate of present study and others

Location/ Country	Ra_{eq} (Bq/kg)	$I_{\gamma r}$	H_{ex}	D (nGy/hr)	References
Thailand	138.6[a]	1.0[a]	0.4[a]	77	[24]
Japan	96.9[a]	0.7[a]	0.3[a]	53	[24]
Xiazhuang, China	266.0	0.3-1.7	0.7	124	[14]
Nile Island, Eqypt	152.9	1.3	0.4[a]	82.7	[23]
Global, 1988	89.2[a]	0.7[a]	0.2[a]	43[a]	[10]
Global, 2000	128.7[a]	0.9[a]	0.3[a]	59	[24]
Malaysia (Peninsular)	208.1[a]	1.5[a]	0.6[a]	92	(UNSCEAR, 2000)
Klang Valley, Malaysia	171.3-563.4 (305.9 ±111.8)	0.7-3.8 (2.3 ±0.8)	0.29-1.50 (0.84 ±0.3)	48.9-244.3 (139.5 ±49.4)	Present study[b]

[a] Calculated by the author by respective data
[b] Value in the bracket is the mean value±SD for 20 sampling sites

4. Conclusions

In this study, 20 soil samples were collected from residential area to determine the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K. The mean activity concentrations of radionuclides were found to be comparable to values from published studies. Radiological hazard with parametric risk such as radium equivalent, radiation hazard index, external hazard index and evaluated total air absorbed dose is within the recommended safe limit. This study was shown that the mean dose equivalent of 0.17 mSv/yr received by an individual at this study area but this value is far below the annual dose limit for public. Thus, former mining soils at P2, P6, P16 and P17 in the studied area were consider having highest potential causing radiation hazard to the people that lives around the area whilst the other locations pose low radiation risks. The data obtained from this study may be useful for the introduction of radiation safety standards by any authorized developers who wants to use this area as a residential area. Thus, the work can be useful insight for authorities to protect public from the radiation hazards in former mining area.

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