Earth Science Research; Vol. 2, No. 2; 2013
ISSN 1927-0542 E-ISSN 1927-0550
Published by Canadian Center of Science and Education

Activity Concentration of ^{238}U, ^{232}Th and ^{40}K Based on Soil Types in Perak State, Malaysia

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Received: March 2, 2013 Accepted: March 21, 2013 Online Published: March 28, 2013

doi:10.5539/esr.v2n2p122 URL: http://dx.doi.org/10.5539/esr.v2n2p122

Abstract

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil samples from different soil types has been collected in the state of Perak, Malaysia. The samples were determined using a high resolution co-axial HPGe gamma ray spectrometry system. Mean values for ^{238}U, ^{232}Th and ^{40}K activity concentrations were found to be (127 ± 97) Bq kg^{-1}, (304 ± 28) Bq kg^{-1}, and (302 ± 29) Bq kg^{-1} respectively. The highest concentration of ^{238}U and ^{232}Th was found for soil of the types Paleudults-Hapludults and ^{40}K for the typic Aeric Tropaquepts. The external hazard values (Hex) are between 0.35 and 3.07. Soil type typic Paleudults and typic Hapludults have a hazard index, H_{ex} value which is greater than 2, and the rest of the soil types (ten soil types) have H_{ex} values between 1 to 2. The concentrations of ^{238}U and ^{232}Th in soil samples in the study area are higher than the reference value.

Keywords: soil types, hazard index, ^{238}U, ^{232}Th, ^{40}K

1. Introduction

The most common terrestrial radioelements that produce gamma-rays are uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K). There are several studies on naturally occurring radionuclide concentrations in normal background radiation areas, including Malanca et al. (1993), Quindos et al. (1994), Narayana et al. (2001), Tufail et al. (2006) and Ramli et al. (2009). The highest concentrations of radioactive minerals in soil are found in Brazil and India (Radhakrishna et al., 1993). The abnormally high terrestrial gamma radiation (HTGR) dose rates in Brazil are due to the presence of monazite sand along the Atlantic coast and volcanic intrusion in the state of Minas Gerais. Dose rate in this area ranged up to 2.1 μGy h^{-1}, which is more than 30 times the world average value (Malanca et al., 1993; Roser & Cullen, 1964).

The concentration value of ^{238}U, ^{232}Th and ^{40}K were varied depends on soil type, geological features and geographical conditions (Florou & Kritidis, 1992; Ramli, 1997). The high natural radiation levels commonly are associated with igneous rocks, such as granite, and lower levels commonly with sedimentary rocks (Tzortzis et al., 2003). The concentrations of uranium and thorium in high background radiation dose rate areas are associated with soil developed from igneous rocks (Kogan et al., 1969; Larsen & Gottfried, 1960). Probably majority of uranium is associated with the phosphatic sands and clays formations (Roessler et al., 1979). The concentrations of the naturally occurring radionuclide of ^{238}U, ^{232}Th and ^{40}K in soil samples were determined in Perak States of Malaysia

2. Soil Type in the Area

The area studied is located between the latitudes of 3°30′ to 5°21′ North, and the longitudes 100°00′ to 101°45′ East, within an area of 21,006 km^2 (Director of National Mapping Malaysia, 1996). The climate is tropical with temperature between 28 °C to 32 °C. The highest point in the area is 2,000 m above sea level. Perak state is overlaid by seven groups of soil series as classified according to the United States Department of Agriculture (USDA) taxonomy name (Director General of Agriculture Peninsular Malaysia, 1973). The groups of soils in Perak state (with local name in brackets) are:

(a) Histosols, are also called organosols, comprising primarily of organic materials. There are two types of histosols in Perak, namely typic Fibric Tropohemists and typic Troposaprits and are known as peat and muck respectively. They are deposited mostly in swampy areas and not far from the coast of the southern parts of Perak state.

(b) Entisols, a group consisting of flood plain material, alluvial soils and sands. Most of this group is found on the coastal plain and in tidal swamps covered by mangrove. Soil series for this group are typic Spodic Quartzipsamment (Jambu), typic Hydraquents (Bakau), typic Sulfaquents (Kranji), typic Tropic Fluvaquents (Briah, Serong, Selangor).

(c) Inceptisols. There are two soils of the inceptosols type, namely typic Aeric Tropaquepts (Akob, Kampong Kubor), and typic Endoaquepts (Merbau patah). These are mostly found in the western part of Perak state.

(d) Oxisols. These have a high concentration of iron, aluminium oxides, hydroxides and sesquioxides. In addition they also contain quartz and kaolin, small amounts of other clay minerals and organic matter. Soil series of this group are typic Hapludoxes (Munchong, Prang).

(e) Ultisols, these soils are quite acidic, often having a pH of less than 5. They are rich in major nutrients, such as calcium and potassium. The types, found in Perak state, are typic Endoaquult (Manik), typic Kandiaquult (Lunas, Sogomana), typic Kandiudults (Sitiawan, Holyrood, Kala), typic Paleudults (Harimau, Serdang, Rengam), Lithic Hapludult (Kedah), and typic Hapludult (Chenian, Bukit Temiang).

(f) Miscellaneous soils. Found in steep lands, these soil types are mostly located in the eastern part of Perak state. Most of the steep lands are in forested areas.

(g) Disturbed land (mined land and urban land).

Soil types according to the USDA soil classification in Perak state, as shown in Table 1.

Table 1. Soil classification according USDA in Perak State

Soil Order	Great Group of Soil (USDA)	Soil Series (local name)	Soil Code (Present study)
Entisols	Typic Spodic Quartzipsamment -Typic Haplorthod	Jambu-Rudua	SC-1
Entisols	Typic Hydraquents	Bakau	SC-2
Entisols	Typic Sulfaquents	Kranji	SC-3
Entisols	Typic Tropic Fluvaquents	Serong	SC-4
Entisols	Typic sulfuric tropic fluvaquent	Kangkong	SC-5
Entisols	Typic Aeric Tropic Fluvaquents	Selangor	SC-6
Entisols	Tropic Fluvaquent- Aeric Tropic Fluvaquent	Briah-Selangor	SC-7
Entisols	Typic Tropic Fluvaquents	Briah	SC-8
Histosols	Typic Troposaprits	Organics Clays and Mucks	SC-9
Histosols	Typic Fibric Tropohemist	Peats	SC-10
Inceptisols	Aeric Tropaquepts-Typic Endoaquepts	Akob-Merbau Patah	SC-11
Inceptisols	Typic Aeric Tropaquepts	Kampong Kubor	SC-12
Entisols	Typic Tropofluvents-Typic Tropopsamment-Aeric Tropaquepts	Local Alluvium -Telemong-Akob	SC-13
Entisols	Typic Tropopsamment-Typic Aeric Tropaquepts	Telemong-Akob	SC-14
Ultisols	Typic endoaquults-Typic Kandiaquults	Manik-Sogomana	SC-15
Ultisols	Typic endoaquults-Typic Kandiaquults	Manik -Lunas	SC-16
Ultisols	Typic Kandiaquult-Typic Kandiudults-Typic Kandiudults	Sogomana-Sitiawan-Holyrood	SC-17
Ultisols	Typic Kandiudults-Typic Paleudults	Holyrood-Harimau	SC-18
Ultisols	Typic Kandiudults-Typic Kandiaquults	Holyrood-Lunas	SC-19
Ultisols	Typic Kandiudults-Typic Kandiaquult-Orthosic Tropudults	Holyrood-Lunas-Kelau	SC-20
Oxisols	Typic Paleudults-Typic Hapludox	Serdang-Munchong	SC-21
Oxisols	Typic Paleudult- Typic Hapludox-Typic Hapludox	Serdang-Munchong-Prang	SC-22
Ultisols	Typic Paleudults-Lithic Hapludults	Serdang-Kedah	SC-23
Ultisols	Typic Kanhapludults	Chenian	SC-24
Ultisols	Typic Kandiudults	Kala	SC-25
Ultisols	Typic Paleudults-Typic Kandiudults	Rengam-Kala	SC-26
Ultisols	Typic Paleudults-Typic Hapludults	Rengam-Bukit Temiang	SC-27
Miscellaneous soils	Miscellaneous soils	Steep Land	SC-28
Disturbed land	Urban and mining land	Disturbed land	SC-29

3. Methods

3.1 Soil Sample Preparation

The soil samples were taken from several different locations and different terrestrial gamma radiation dose rate in Perak State, Malaysia. Soil samples preparation and materials were described elsewhere (Ramli et al., 2009). ^{238}U, ^{232}Th and ^{40}K concentration in soil samples were determined by a coaxial high purity germanium (HPGe) gamma ray spectrometer. The IAEA reference nuclides ^{133}Ba, ^{22}Na, ^{137}Cs, ^{60}Co and ^{152}Eu were used for calibration. The IAEA standard samples, SL-14 and SL-2 were used as reference materials and were mixed with SiO_2 in Marinelli beakers. The activity concentration in soil samples (in *Bq kg* $^{-1}$) due to radionuclide *i* and for a peak at energy *E*, was calculated by using Equation (1),

$$A_{Ei} = \frac{N_{Ei}}{\varepsilon_{Ei}\ \mathrm{t}\ \gamma_{Ei}\ M} \quad (1)$$

where N_{Ei} is the net peak area at energy *E of radionuclide i*, ε_{Ei} is the detection efficiency, *t* is the counting time, γ is the number of gammas per nuclear transformation, and *M* is the mass in *kg* of the measured sample.

3.2 Radiological Hazard Index

To determine the relative hazard of materials that contain ^{238}U, ^{232}Th and ^{40}K were used by the radium-equivalent activity Ra_{eq} as shown in Equation (2) (Krieger, 1981; Beretka & Mathew, 1985),

$$Ra_{eq} = 370\ \mathrm{Bq\ kg^{-1}}\ H_{ex} \quad (2)$$

where, H_{ex} is the external hazard index which is calculated by using Equation (3),

$$H_{ex} = \frac{C_u}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \le 1 \quad (3)$$

where C_U, C_{Th}, and C_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq kg^{-1} respectively. H_{ex} can be considered to be low if its value is less than or equal to 1 (Krieger, 1981; Beretka & Mathew, 1985). The index value of 1 is equivalent to 370 Bq kg^{-1} of radium. This will cause a radiation dose of 1.5 mSv per year which has been considered as an acceptable radiation dose level due to Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) for member of the public (ICRP, 1991).

4. Results and Discussion

The dose conversion factors obtained as shown in Table 2. The results were compared with various reported values. Conversation factors obtained in this study are in good agreement with those of earlier studies. Statistical testing was used to evaluate the results from this study with respect to published values. The results obtained are comparable with the published values if $p > 0.05$ or t-test value < t-table value by Student's *t*-test. The test results obtained indicated that no significant difference exist between the results obtained by present study and the earlier studies. Therefore the dose conversion factors obtained can be used to predict terrestrial gamma radiation dose rate from ^{238}U, ^{232}Th and ^{40}K concentration, or more practically to check the validity of measurements done when direct instrumental calibration with respect ultra low environmental doses is impractical (Ramli et al., 2005).

The mean values of ^{238}U, ^{232}Th and ^{40}K activity concentrations in different soil types in Perak State are presented in Table 2. The activity concentrations of the soil samples for ^{238}U ranged from 7 Bq kg^{-1} to 554 Bq kg^{-1}, with the mean value of (127 ± 97) Bq kg^{-1}; for ^{232}Th ranged from 23 Bq kg^{-1} to 1 806 Bq kg^{-1}, with the mean value of (304 ± 28) Bq kg^{-1}; and for ^{40}K ranged from 6 Bq kg^{-1} to 2,522 Bq kg^{-1}, with the mean value of (302 ± 29) Bq kg^{-1}. The average activity concentrations of ^{238}U and ^{232}Th are higher than the world. But, the activity concentration for ^{40}K is lower than world average value of 400 Bq kg^{-1}. The most abundant radionuclide is thorium (^{232}Th). It is about 42% of the total (^{232}U + ^{232}Th + ^{40}K), ^{238}U is 17% and ^{40}K is 41%. The activity concentrations of ^{232}U, ^{232}Th and ^{40}K in different of soil samples are given in Figure 1.

Table 2. Dose conversion factors for ^{238}U, ^{232}Th and ^{40}K were given in the literature and as derived from experimental data

Radioelement	Dose conversion factors (nGy h^{-1} per Bq kg^{-1})					t-test	p-value
	Saito[1]	Beck[2]	Clouvas[3]	Jibiri[4]	Present Work		
^{238}U	0.463	0.43	0.399	0.429	0.4076	2.45	0.07
^{232}Th	0.604	0.666	0.5437	0.666	0.6523	1.66	0.17
^{40}K	0.0417	0.0422	0.0399	0.042	0.0421	0.72	0.51

([1]Saito & Jacob, 1995; [2]Beck et al., 1972; [3] Clouvas et al., 2000; [4]Jibiri, 2001)

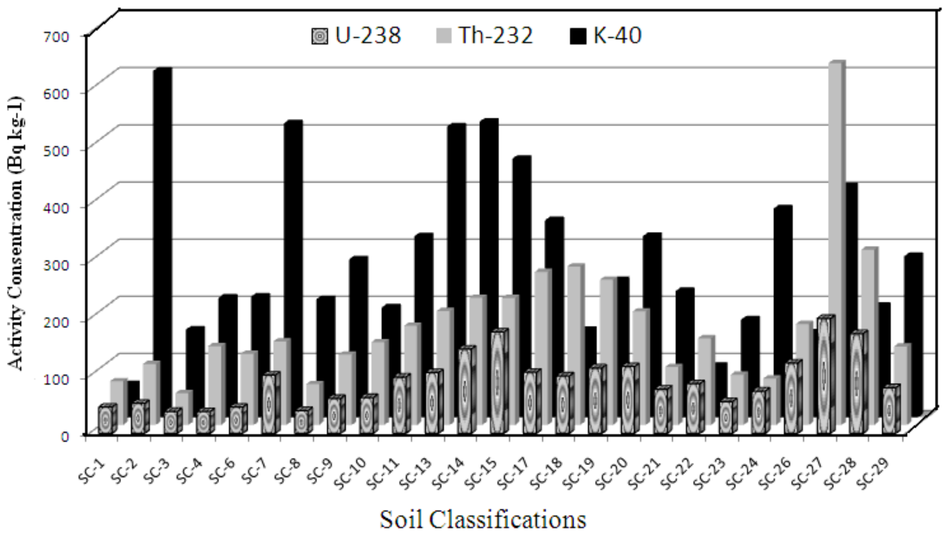

Figure 1. The activity concentration of ^{238}U, ^{232}Th, and ^{40}K in soil classifications

The calculated external hazard values are between 0.35 and 3.07. They are given in Table 3. Fourteen of the soil types have values lower than unity. They cover 62% Perak state. They are not considered to pose significant radiological hazard. Conversely, soil type typic Paleudults and typic Hapludults have a hazard index, H_{ex} value which is greater than 2. They are found in 11% of the Perak state. The rest of the soil types (ten soil types) are found in 27% of the area and have H_{ex} values between 1 to 2. Thus according to ICRP 1991 recommendations, caution has to be taken if these soil types or its derivatives are to be incorporated as building materials, especially those from the typic Paleudults and typic Hapludults type.

5. Conclusion

The results indicate that the concentration of ^{238}U and ^{232}Th in soil samples are higher than the reference values by UNSCEAR 2000. The mean activity concentration was higher for soils of granitic origin (typic Paleudult-typic Hapludult locally known as Renggam-Bukit Temiam and miscellaneous soil), and lower for soils originating from shale and alluvium (Tropic Fluvaquent locally known as Serong and Aeric Tropic Fluvaquents locally known as Selangor).

The results obtained on hazard index, H_{ex} for various soil types in Perak state indicate that caution needs to taken for most of the soil types if they or their derivatives are to be used as building material.

Table 3. Specific concentration of ^{238}U, ^{232}Th and ^{40}K, Hazard Index, and Radium equivalent activity in soil samples

Great group of soil classification (USDA Classifications)	N	Concentrtion (Bq kg^{-1}) ± SE			Hazard Index, H_{ex}	Radium equivalen activity, R_{aq}
		^{238}U	^{232}Th	^{40}K		
Typic Spodic Quartzipsamment -Typic Haplorthod	2	4 ± 12	77 ± 18	56 ± 4	0.43	160
Typic Hydraquents	3	53 ± 11	107 ± 28	604 ± 202	0.68	251
Typic Sulfaquents	2	39 ±16	56 ± 5	151 ± 90	0.35	129
Typic Tropic Fluvaquents	2	38 ± 4	138 ± 19	207 ± 32	0.68	251
Typic Aeric Tropic Fluvaquents	2	46 ± 5	125 ± 4	209 ± 140	0.65	240
Tropic Fluvaquent- Aeric Tropic Fluvaquent	2	102 ± 35	146 ± 26	512 ± 37	0.95	350
Typic Tropic Fluvaquents	3	40 ± 16	71 ± 16	205 ± 105	0.43	158
Typic Troposaprits	2	61 ± 18	123 ± 26	274 ± 41	0.70	258
Typic Fibric Tropohemist	8	63 ± 13	145 ± 62	190 ± 88	0.77	284
Typic Aeric Tropaquepts-Typic Endoaquepts	2	99 ± 32	174 ± 85	315 ± 213	1.00	371
Typic Tropofluvents-Typic Tropopsamment-Aeric Tropaquepts	7	106 ± 32	199 ± 56	507 ± 107	1.16	430
Typic Tropopsamment-Typic Aeric Tropaquepts	6	148 ± 44	222 ± 55	515 ± 80	1.36	505
Typic endoaquults-Typic Kandiaquults	2	178 ± 65	222 ± 14	450 ± 145	1.43	529
Typic Kandiaquult-Typic Kandiudults-Typic Kandiudults	2	107 ± 20	268 ± 50	343 ± 47	1.39	515
Typic Kandiudults-Typic Paleudults	4	101 ± 12	277 ± 120	151 ± 49	1.37	508
Typic Kandiudults-Typic Kandiaquults	16	114 ± 22	254 ± 69	238 ± 83	1.34	496
Typic Kandiudults-Typic Kandiaquult-Orthosic Tropudults	2	117 ± 63	199 ± 39	315 ± 74	1.15	425
Typic Paleudults-Typic Hapludox	13	77 ± 19	101 ± 24	219 ± 74	0.65	239
Typic Paleudult-Typic Hapludox-Typic Hapludox	2	87 ± 16	152 ± 1	88 ± 13	0.84	310
Typic Paleudults-Typic Lithic Hapludults	3	56 ± 18	88 ± 21	169 ± 25	0.52	194
Typic Kanhapludults	2	74 ± 20	81 ± 21	363 ± 58	0.59	218
Typic Paleudults-Typic Kandiudults	2	123 ± 16	177 ± 57	146 ± 119	1.04	386
Typic Paleudults-Typic Hapludults	38	201 ± 17	633 ± 78	402 ± 85	3.07	1,136
Miscellaneous soils (Steep Land)	14	174 ± 26	306 ± 51	193 ± 51	1.69	627
Urban and mining land (Disturbed Land)	16	80 ± 12	137 ± 20	280 ± 83	0.80	297
Perak state	157	127 ± 97	304 ± 28	302 ± 29		
		(7-554)	(23-1 806)	(6-2 522)		
Malaysia (Unscear, 2000)		66 (49-86)	82 (63-110)	310 (170-430)		
World (Unscear, 2000)		35 (16-110)	30 (11-64)	400 (140-850)		

Acknowledgment

The project is funded by The Atomic Energy Licensing Board of Malaysia (vot no. 68876). This project also used various facilities provided by Universiti Teknologi Malaysia, The Malaysian Nuclear Agency, and The National Nuclear Energy Agency of Indonesia (BATAN).

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