AN ASSESSMENT OF ABSORBED DOSE AND RADIATION HAZARD INDEX FROM NATURAL RADIOACTIVITY

Masitah Alias[1], Zaini Hamzah[1], Ahmad Saat[1], Mohamat Omar[2] and Abdul Khalik Wood[2]

[1]*Faculty of Applied Sciences, Universiti Teknologi MARA, 40450 Shah Alam, Selangor Darul Ehsan*
[2]*Malaysian Institute for Nuclear Technology Research, 43000, Bangi, Selangor Darul Ehsan.*
e-mail: ellyaa@yahoo.com

Keywords: *Natural radionuclides, absorbed dose rate, radiation hazard index, gamma spectrometer, NAA.*

Abstract

Naturally occurring radionuclides such as ^{40}K, ^{226}Ra and ^{228}Ra which emit gamma radiation through their decaying process could reach the human in vicinity. The study area was chosen for its variety of surface conditions such as slope, flat land catchments and also forest area, which is used as a reference place. Soil samples were collected using hand auger, and the sampling positions were determined using a Global Positioning System (GPS). The amount of radioactivity concentration of these radionuclides is the important factor in assessing whether it is harmful or otherwise. In this study, the surface doses rate measurements were done in-situ using dose rate meter, and the radioactivity concentration levels were done by counting the soil samples using gamma spectrometer with HPGe detector in the laboratory. The amount of uranium, thorium and potassium in soil were determined using neutron activation analysis (NAA) technique. The results show a reasonably low radiation absorb dose and radiation hazard index, which is a good indication for the farmers to work in the area.

Abstrak

Radionuklida semulajadi seperti ^{40}K, ^{226}Ra dan ^{228}Ra yang memancarkan sinar gama melalui proses pereputannya boleh mengenai manusia yang berhampirannya. Kawasan kajian ini telah dipilih berdasarkan keadaan permukaan tanah yang berbeza seperti tanah rata, cerun, dan kawasan rendah yang berpaya serta kawasan hutan untuk dijadikan kawasan rujukan. Sampel tanah telah dipungut menggunakan auger dan lokasi pensampelan ditentukan dengan menggunakan sistem penempatan global (GPS). Jumlah kepekatan radioaktiviti dari radionuklida ini adalah faktor penting bagi menentukan samada ianya berbahaya atau tidak. Dalam kajian ini, pengukuran radioaktiviti dalam makmal dilakukan dengan membilang sampel tanah menggunakan spektrometer gama dilengkapkan dengan pengesan HPGe. Jumlah uranium, thorium dan kalium di dalam tanah ditentukan dengan teknik analisis pengaktifan neutron. Hasil kajian menunjukkan kadar serapan dan indeks radiasi berbahaya yang agak rendah yang menunjukkan indikasi yang baik untuk petani yang bekerja di kawasan tersebut.

Introduction

Over 60 radionuclides (radioactive elements) can be found in nature, and they can be placed in three general categories i.e. Primordial - formed before the creation of the Earth, Cosmogenic - formed as a result of cosmic ray interactions, and Human Produced - enhanced or formed due to human actions (minor amounts compared to natural). Radionuclides are found naturally in air, water and soil. They are even found in us, being that we are products of our environment. Every day, we ingest and inhale radionuclides in our air, food and the water. Natural radioactivity is common in the rocks and soil that makes up our planet, in water and oceans, and in our building materials and homes. There is nowhere on Earth that we can not find natural radioactivity [1].

Some radioactive nuclides are detectable in soil. They belong to the natural radionuclides like the members of the uranium and thorium decay series. More specifically, natural environment radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world [2,3]. The specific levels of terrestrial environmental radiation are related to the geological composition of each lithologically separated area, and to the content of the rock from which the soils originated in each area in the radioactive elements of thorium (Th), uranium (U) and potassium (K). It is well known, for instance, that igneous rocks of granitic composition are strongly enriched in Th and U (on average 15 μgg^{-1} of Th and 5 μgg^{-1} of U), as compared to rocks of basaltic or ultramafic composition (< 1μgg^{-1} of U) [2,9,10]. For that reason, higher radiation levels are associated with igneous rock and lower level with sedimentary rocks. There are exceptions, however, as some shales and phosphate rocks have relatively high content of those radionuclides [2,3].

Uranium minerals are chemically weathered to soluble U(VI) complexes and carried by river water downstream to the oceans, while the primary mode for transport of thorium from the continents to the oceans follow the detrital phase [4,5]. The residence time for thorium in sea water is only approximately 300-350 years. Uranium remains soluble in the sea (as carbonate and other complexes) and has a residence time in sea water of some 500 000 years [6].

Precipitation of uranium can occur easily by reduction to insoluble U(IV). Thus, environments in which carbonaceous and bituminous shales form are particularly favourable for U removal by reduction of U(VI) to U(IV). Lignites are also enriched in uranium, some as U(IV), as expected, and some as U(VI) because the latter form can easily be scavenged by 'coaly' material without reduction. This accounts, in part, for the high U content of such rock. In the case of phosphotic rocks, co-precipitation of U(IV) with Ca^{2+} is likely owing to their very similar ionic radii, but the exact mechanism for the reduction of U(VI) to U(IV) in these rocks is not known [6].

Th/U ratio in nature varies widely. In rocks from which U has been removed, high Th/U ratio results; conversely, in rocks precipitated under chemically reducing environments far from suspected rock source, U is enriched over thorium. Thus, above average Th/U ratios are observed in continental sediments, especially in laterites and other residual deposits. Low Th/U ratios are found in chemically precipitated marine sedimentary rock, such as evaporate sand, limestone, and extremely low Th/U ratios are found in carbonaceous rock . [6].

Human beings have always been exposed to natural radiations from their surrounding. The exposure to ionizing radiations from natural sources occurs because of naturally occurring radioactive elements in the soil and rocks, cosmic rays entering the earth's atmosphere from outer space and the internal exposure from radioactive elements through food, water and air. Therefore the assessment of gamma radiation dose from natural sources is of particular importance as natural radiation is the largest contributor to the external dose of the world population [7].

The objectives of this research project are to determine the radioactivity concentrations of ^{40}K, ^{226}Ra and ^{228}Ra in top soil and depth soil samples, to measure the surface radiation dose rate, to determine the concentration of uranium, thorium and potassium in topsoil samples, to evaluate the level of radioactivity concentrations and their relation with soil texture, physical and chemical properties of soil, and to estimate the radiation absorbed dose, effective annual dose, radium equivalent activity and radiation hazard index from the radioactivity measured in the study area.

Experimental

Sampling and Sample Preparation

The sampling area was an oil palm area located at Jengka 15, Pahang, Malaysia. The sampling technique was in accordance of the California Standard Operating Procedure [8]. The sampling was done in a zig-zag pattern comprising 50 sampling points for topsoil (up to 6cm) and 7 points for depth profile (up to 20 cm). From each point, five representative samples were collected at equal distance along the 1 m circumference around the point. This will improve the representative homogeneity of sample from each sampling point. The distance between each point was about 40 meters. The position and elevation of each sampling points was determined using a global positioning system (GPS). Soil samples were taken to the lab and cleaned from plant roots and other foreign materials. Samples were dried in an oven at 60°C or air dried for a few days. Samples were grounded and sieved using 2 mm sieve to get the homogeneous samples. About 400 g of dry sample was weighed into a plastic container, capped, sealed and then labeled.

Measurement of Activity Concentrations of Radionuclides in Top Soils: ^{40}K, ^{226}Ra, and ^{228}Ra.

The samples were kept at room temperature for three weeks to allow the natural radionuclides to achieve equilibrium. A same amount of IAEA (soil-6) prepared in the same manner was used as standard reference material. The measurements were made using a gamma ray HPGe counting system calibrated using ^{57}Co, ^{137}Cs, ^{133}Ba, ^{85}Sr, ^{54}Mn, ^{88}Y and ^{65}Zn for two hours. Counting efficiency of the counting system used was determined previously for all of its counting geometry. The measurements were carried out using facilities in Malaysian Nuclear Agency, Bangi. The radionuclides were identified according to their individual photo peak which are energy peaks 295, 352 and 609 keV used to determine ^{226}Ra. Energy peak 911 keV was used to determine ^{228}Ra while 1462 keV was used to determine ^{40}K. The concentration of the individual radionuclide was calculated by using the following formula:

$$W_S = \frac{M_p \times A_S \times W_p}{M_S \times A_p} \qquad \text{where}$$

W_s; the concentration of the radionuclides in sample (Bq/kg)
W_p; the concentration of the radionuclides in standard (Bq/kg)
M_s ; the weight of the sample (g),
M_p ; the weight of the standard (g)
A_s ; the counting of the samples (cps); and,
A_p; the counting of the standard (cps)

Surface Dose Rate

The surface doses rate were measured in-situ at each sampling point using LUDLUM rate meter. The detector was placed 1 meter above the ground when taking the reading. The meter was pre calibrated before taking it to the field.

Results and Discussion

Radionuclides Activity Concentrations

Table1 lists the radionuclide activity concentrations for ^{40}K, ^{226}Ra and ^{228}Ra in forest, flat, slope and catchments area. 50 samples were analyzed and it gives the means activity concentrations of ^{40}K, ^{226}Ra and ^{228}Ra.

Table 1: Radionuclides (^{40}K, ^{226}Ra, and ^{228}Ra) activity concentrations in top soils

Sample Code	North	South	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)	^{228} Ra (Bq/kg)
			Forest Area		
F$_{R}$SP$_{1}$	03^{0}44.362’	102^{0}34.000’	45.9 ± 11.9	16.9 ± 9.6	37.1 ± 3.7
F$_{R}$SP$_{2}$	03^{0}44.386’	102^{0}33.967’	217.6 ± 36.5	18.3 ± 5.7	26.7 ± 2.3
F$_{R}$SP$_{3}$	03^{0}44.350’	102^{0}33.968’	55.3 ± 17.1	12.6 ± 7.9	28.8 ± 2.7
F$_{R}$SP$_{4}$	03^{0}44.349’	102^{0}33.975’	124.8 ± 21.4	23.8 ± 5.4	31.5 ± 2.2
F$_{R}$SP$_{5}$	03^{0}44.348’	102^{0}33.980’	89.7 ± 18.7	23.0 ± 1.1	42.0 ± 3.9
F$_{R}$SP$_{6}$	03^{0}44.355’	102^{0}33.990’	152.4 ± 20.2	25.2 ± 1.2	33.9 ± 2.4
F$_{R}$SP$_{7}$	03^{0}44.361’	102^{0}34.003’	234.5 ± 29.6	24.3 ± 1.3	35.2 ± 3.6
F$_{R}$SP$_{8}$	03^{0}44.339’	102^{0}33.993’	87.1 ± 13.3	23 ± 0.6	35.5 ± 2.2
	Range		45.9 - 234.5	12.6 - 25.2	26.7 - 42.0
	Mean		125.9 ± 21.1	20.9 ± 4.1	33.8 ± 2.9
			Flat Area		
F$_{1}$CLSP$_{1}$	03^{0}44.350’	102^{0}33.909’	45.9 ± 11.9	10.5 ± 0.7	16.3 ± 2.3
F$_{1}$CLSP$_{2}$	03^{0}44.402’	102^{0}33.806’	68.4 ± 14.0	19.8 ± 1.0	24.9 ± 2.4
F$_{1}$CLSP$_{3}$	03^{0}44.401’	102^{0}33.790’	45.4 ± 11.8	10.1 ± 0.8	12.0 ± 2.4
F$_{1}$CLSP$_{4}$	03^{0}44.391’	102^{0}33.874’	61.8 ± 11.9	19.2 ± 0.9	26.1 ± 2.8
F$_{1}$CLSP$_{5}$	03^{0}44.380’	102^{0}33.822’	46.3 ± 7.5	10.7 ± 0.7	15.8 ± 2.4
F$_{1}$CLSP$_{6}$	03^{0}44.396’	102^{0}33.816’	156.6 ± 17.3	29.3 ± 0.8	39.1 ± 2.9
	Range		45.4 - 156.6	10.1 - 29.3	12.0 -39.1
	Mean		70.7 ± 12.4	16.6 ± 0.8	22.4 ± 2.5
			Flat Area		
F$_{2}$CLSP$_{1}$	03044.371’	102033.897’	44.8 ± 8.6	16.3 ± 0.4	29.8 ± 2.6
F$_{2}$CLSP$_{2}$	03044.365’	102033.903’	42.2 ± 9.3	12.6 ± 0.9	20.9 ± 2 .8
F$_{2}$CLSP$_{3}$	03044.356’	102033.917’	84.0 ± 10.6	14.7 ± 0.8	27.9 ± 3.0
F$_{2}$CLSP$_{4}$	03044.359’	102033.902’	46.2 ± 11.1	19.1 ± 1.0	29.1 ± 3.4
F$_{2}$CLSP$_{5}$	03044.385’	102033.880’	59.9 ± 7.2	16.1 ± 0.4	21.7 ± 1.3
F$_{2}$CLSP$_{6}$	03^{0}44.380’	102^{0}33.904’	23.9 ± 6.1	31.6 ± 0.7	34.0 ± 2.1
F$_{7}$CLSP$_{7}$	03^{0}44.362’	102^{0}33.896’	98.4 ± 13.6	16.8 ± 1.0	29.8 ± 3.3
F$_{2}$CLSP$_{8}$	03^{0}44.364’	102^{0}33.881’	29.8 ± 10.2	15.2 ± 1.0	22.7 ± 3.0
F$_{2}$CLSP$_{9}$	03^{0}44.381’	102^{0}33.886’	70.0 ± 12.2	18.9 ± 1.0	26.3 ± 2.1
	Range		23.9 - 98.4	12.6 - 31.6	21.7 – 34.0
	Mean		55.5 ± 10.9	17.9 ± 0.8	26.9 ± 2.6

Table 1: Radionuclides (^{40}K, ^{226}Ra, and ^{228}Ra) activity concentrations in top soils (cont'd)

Sample Code	North	South	^{40}K (Bq/kg)	^{226}Ra (Bq/kg)	^{228} Ra (Bq/kg)
			Slope Area		
S_1CLSP_1	03^{0}44.380’	102^{0}33.771’	50.4 ± 16.2	23.5 ± 2.2	32.8 ± 5.3
S_1CLSP_2	03^{0}44.361’	102^{0}33.785’	69.7 ± 14.4	30.3 ± 1.8	27.5 ± 5.4
S_1CLSP_3	03^{0}44.367’	102^{0}33.809’	51.2 ± 17.8	22.2 ± 2.3	42.8 ± 4.5
S_1CLSP_4	03^{0}44.392’	102^{0}33.775’	49.8 ± 17.5	20.6 ± 2.1	32.8 ± 6.0
S_1CLSP_5	03^{0}44.381’	102^{0}33.791’	108.3 ± 15.5	21.3 ± 1.1	25.7 ± 2.9
S_1CLSP_6	03^{0}44.362’	102^{0}33.771’	108.4 ± 15.2	21.2 ± 1.0	25.6 ± 2.9
S_1CLSP_7	03^{0}44.330’	102^{0}33.871’	48.9 ± 6.6	15.8 ± 0.4	22.0 ± 1.3
S_1CLSP_8	03^{0}44.321’	102^{0}33.852’	71.0 ± 14.8	16.6 ± 1.0	17.6 ± 2.5
S_1CLSP_9	03^{0}44.336’	102^{0}33.771’	52.1 ± 5.5	16.3 ± 0.3	25.2 ± 1.3
S_1CLSP_{10}	03^{0}44.330’	102^{0}33.820’	102.3 ± 23.7	36.5 ± 2.4	41.3 ± 5.3
S_1CLSP_{11}	03^{0}44.330’	102^{0}33.897’	11.3 ± 1.3	14.8 ± 1.8	20.0 ± 4.3
S_1CLSP_{12}	03^{0}44.327’	102^{0}33.859’	51.8 ± 6.0	11.3 ± 0.3	17.8 ± 1.2
S_1CLSP_{13}	03^{0}44.351’	102^{0}33.916’	34.7 ± 9.6	11.7 ± 0.8	18.9 ± 2.1
S_1CLSP_{14}	03^{0}44.375’	102^{0}33.771’	50.5 ± 11.2	19.6 ± 1.5	29.1 ± 3.4
	Range		11.3 - 108.4	11.3 – 36.5	17.8 – 42.8
	Mean		61.5 ± 12.5	20.1 ± 1.4	27.1 ± 3.5
S_2CLSP_1	03^{0}44.321’	102^{0}33.925’	52.1 ± 13.1	14.0 ± 1.0	22.8 ± 2.9
S_2CLSP_2	03^{0}44.325’	102^{0}33.942’	78.3 ± 11.5	18.7 ± 11.5	27.5 ± 3.4
S_2CLSP_3	03^{0}44.344’	102^{0}33.945’	126.4 ± 12.4	18.7 ± 0.5	18.7 ± 1.7
S_2CLSP_4	03^{0}44.358’	102^{0}33.940’	72.4 ± 13.1	16.5 ± 0.9	16.5 ± 0.9
S_2CLSP_5	03^{0}44.326’	102^{0}33.904’	14.2 ± 6.7	18.0 ± 0.8	28.6 ± 1.8
S_2CLSP_6	03^{0}44.343’	102^{0}33.880’	59.1 ± 19.2	35.3 ± 2.2	38.2 ± 4.6
S_2CLSP_7	03^{0}44.334’	102^{0}33.925’	32.0 ± 8.0	10.5 ± 0.7	11.4 ± 1.2
S_2CLSP_8	03^{0}44.338’	102^{0}33.909’	60.5 ± 12.5	18.9 ± 1.1	32.5 ± 3.6
	Range		32.0 – 126.4	14.0 – 35.3	11.4 – 38.2
	Mean		61.9 ± 12.8	18.8 ± 1.7	24.5 ± 3.1
			Catchment area		
$W1_1CLSP_1$	03^{0}44.278’	102^{0}33.839’	258.5 ± 29.6	16.2 ± 1.1	35.5 ± 28.2
W_1CLSP_2	03^{0}44.255’	102^{0}33.906’	300.3 ± 32.4	16.2 ± 0.8	38.9 ± 4.0
W_1CLSP_3	03^{0}44.366’	102^{0}33.857’	383.8 ± 41.4	19.7 ± 1.1	36.2 ± 4.2
W_1CLSP_4	03^{0}44.349’	102^{0}33.924’	165.4 ± 18.4	16.2 ± 0.8	27.3 ± 26.0
W_1CLSP_5	03^{0}44.373’	102^{0}33.771’	107.2 ± 13.4	42.0 ± 1.5	44.9 ± 3.7
	Range		107.2 - 383.8	16.2 - 42.0	27.3 - 44.9
	Mean		243.0 ± 27.0	22.1 ± 1.1	36.6 ± 13.2

The mean activity concentrations of ^{40}K are 125.9 ± 21.1, 70.7 ± 12.4, 55.5 ± 10.9, 61.5 ± 12.5, 61.9 ± 12.8, and 243.0 ± 27.0 Bqkg^{-1} for forest, flat 1 , flat 2, slope 1, slope 2 and catchment areas respectively. The mean activity concentrations of ^{226}Ra are 20.9 ± 4.1, 16.6 ± 0.8, 17.9 ± 0.8, 20.1 ± 1.4, 18.8 ± 1.7, and 22.1 ± 1.1 Bqkg^{-1} for forest, flat 1, flat 2, slope 1, slope 2 and catchments areas respectively. The mean activity concentrations of ^{228}Ra are 33.8 ± 2.9, 22.4 ± 2.5, 26.9 ± 2.6, 27.1 ± 3.5, 24.5 ± 3.1, and 36.6 ± 13.2 Bqkg^{-1} for forest, flat 1 , flat 2, slope 1, slope 2 and catchments areas respectively.

Figure 1 below, summarizes the means activity concentrations for ^{40}K, ^{226}Ra and ^{228}Ra in top soil samples. It shows the accumulation effect of the activity concentrations in the catchment area. This could be due to run off activities in the area where the amount of rainfall in the area is more than 300 mm per year.

Surface Dose Rate

Table 2 lists the ratio of ^{226}Ra/^{228}Ra activity concentration, surface dose rate and radium equivalent, Ra_{eq} for top soil samples. The ratio of ^{226}Ra/^{228}Ra concentration activities is less than 1 because the concentration activity of ^{226}Ra in soil is less than concentration activity of ^{228}Ra. In other word, the concentration of uranium in soil is less then thorium, since uranium and thorium are the parent of ^{226}Ra and ^{228}Ra respectively.

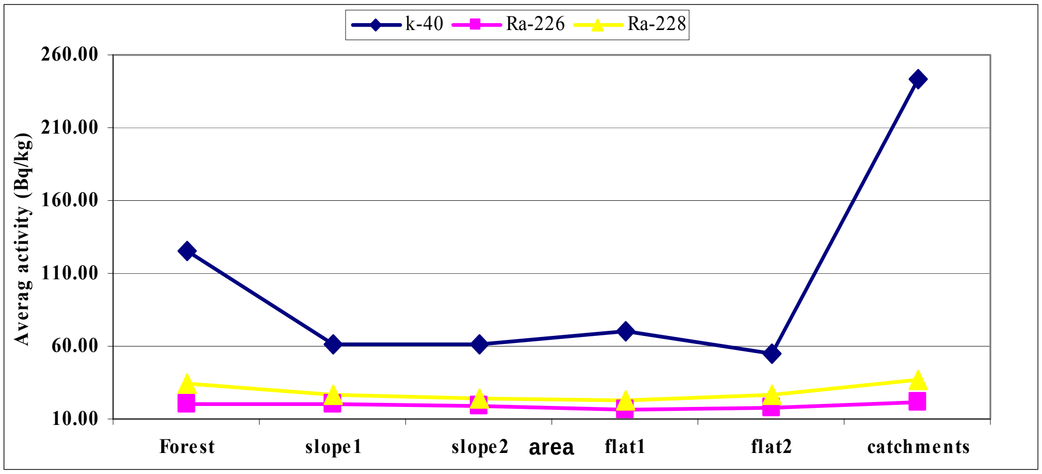

Figure 1. Means activity concentration for ^{40}K, ^{226}Ra and ^{228}Ra in top soil samples

Radium equivalent is defined as,

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.07C_K$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. While defining Ra_{eq} activity, it has been assumed that 370 Bqkg^{-1}, ^{226}Ra or 259 Bqkg^{-1} ^{232}Th or 4810 Bqkg^{-1} ^{40}K produce the same gamma rate to compare the specific activity of materials containing different amounts of ^{226}Ra, ^{228}Ra and ^{40}K.

Table 2. The ratio ^{226}Ra/^{228}Ra, Surface dose rate and Radium equivalent activity

Code Sample	Ratio ^{226}Ra/^{228}Ra	Surface Dose Rate (μSv/hr)	Ra_{eq} activity (Bq/kg)
		Forest	
F_RSP_1	0.46	0.224	73.17
F_RSP_2	0.68	0.191	71.71
F_RSP_3	0.43	0.159	57.66
F_RSP_4	0.75	0.107	77.58
F_RSP_5	0.55	0.204	89.34
F_RSP_6	0.74	0.161	84.35
F_RSP_7	0.69	0.118	91.05
F_RSP_8	0.65	0.114	79.86
Range		0.107 – 0.224	57.7-91.1
Mean		0.160	78.1
		Flat area	
F_1CLSP_1	0.64	0.084	37.02
F_1CLSP_2	0.80	0.176	60.20
F_1CLSP_3	0.84	0.057	30.44
F_1CLSP_4	0.74	0.160	60.85
F_1CLSP_5	0.68	0.125	36.54
F_1CLSP_6	0.75	0.188	96.18
Range		0.057-0.188	30.44 – 96.18
Mean		0.132	53.5
F_2CLSP_1	0.55	0.135	62.05
F_2CLSP_2	0.60	0.139	45.44
F_2CLSP_3	0.53	0.105	60.48
F_2CLSP_4	0.66	0.124	63.95
F_2CLSP_5	0.74	0.117	51.32
F_2CLSP_6	0.93	0.127	81.89
F_7CLSP_7	0.56	0.101	66.30
F_2CLSP_8	0.67	0.129	49.75
F_2CLSP_9	0.72	0.125	61.41
Range		0.101-0.139	45.44 - 81.89
Mean		0.122	60.3

Code Sample	Ratio $^{226}Ra/^{228}Ra$	Surface Dose Rate (μSv/hr)	Ra_{eq} activity (Bq/kg)
		Slope area	
S_1CLSP_1	0.72	0.100	73.93
S_1CLSP_2	0.91	0.106	74.50
S_1CLSP_3	0.52	0.156	86.99
S_1CLSP_4	0.63	0.099	70.99
S_1CLSP_5	0.83	0.152	65.63
S_1CLSP_6	0.83	0.099	65.40
S_1CLSP_7	0.71	0.100	50.68
S_1CLSP_8	0.94	0.112	46.74
S_1CLSP_9	0.65	0.190	55.98
S_1CLSP_{10}	0.88	0.105	102.72
S_1CLSP_{11}	0.74	0.100	44.19
S_1CLSP_{12}	0.64	0.121	40.38
S_1CLSP_{13}	0.62	0.172	41.16
S_1CLSP_{14}	0.67	0.137	64.8
	Range	0.099-0.190	41.16-102.72
	Mean	0.125	63.15
S_2CLSP_1	0.62	0.132	50.25
S_2CLSP_2	0.68	0.129	63.51
S_2CLSP_3	0.56	0.100	54.29
S_2CLSP_4	0.79	0.130	45.16
S_2CLSP_5	0.63	0.200	59.89
S_2CLSP_6	0.92	0.132	94.06
S_2CLSP_7	0.92	0.098	29.04
S_2CLSP_8	0.58	0.195	69.61
	Range	0.098 – 0.200	29.04-94.06
	Mean	0.140	58.2
		Catchments area	
$W1_1CLSP_1$	0.46	0.130	85.06
W_1CLSP_2	0.42	0.115	92.85
W_1CLSP_3	0.54	0.130	98.33
W_1CLSP_4	0.59	0.136	66.82
W_1CLSP_5	0.94	0.102	113.71
	Range	0.102 – 0.136	66.8 - 113.7
	Mean	0.123	91.4

The mean surface does rate for various sections in the area are 0.160, 0.132, 0.122, 0.125, 0.140, and 0.123 μSvhr^{-1} for forest, flat 1, flat 2, slope 1, slope 2, and catchment areas respectively. The mean radium equivalent Ra_{eq} are 78.1, 53.5, 60.3, 63.15, 58.2, and 91.4 Bqkg^{-1} for forest, flat 1, flat 2, slope 1, slope 2, and catchment areas respectively. Figure 2 below shows the radium equivalent activity in Bqkg^{-1} for various sections in the study area. The catchment area shows an enrichment of activity, since it is the low land and it is collecting all the eroded soil carried by the run off water. Therefore, the radionuclides tend to accumulate in the catchment area giving the highest radium equivalent activity.

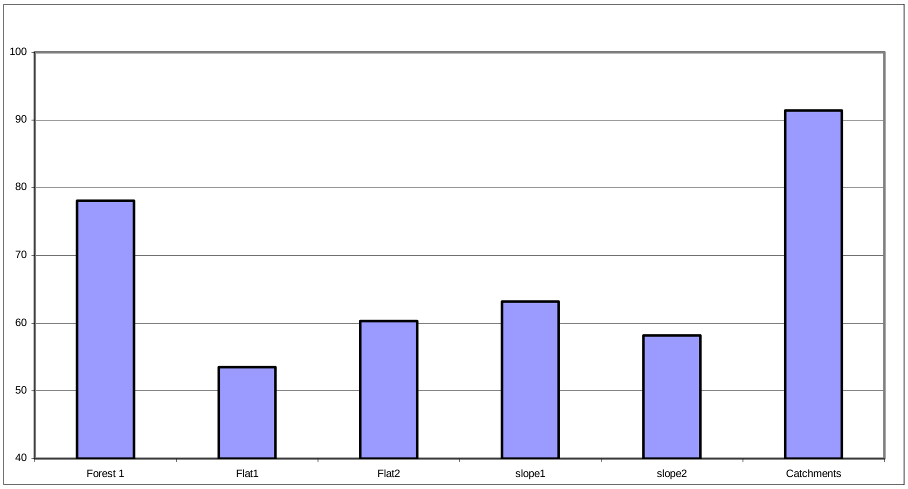

Figure 2:. Radium equivalent activity in Bq/kg for various sections in the study area

Absorbed Dose Rate ,Annual Effective Dose and External Hazard Index

Table 3 lists the air absorbed dose rate, external hazard index H_{ex} and annual effective dose for various sections in the study area. The outdoor air-absorbed dose rates due to terrestrial gamma rays at 1 m above the ground were calculated from ^{226}Ra, ^{232}Th and ^{40}K concentration values in soil assuming that the other radionuclides, such as ^{137}Cs, ^{90}Sr and ^{235}U decay series can be neglected as they contribute very little to the total dose from environmental background [11,12,13]. The conversion factors used to calculate the absorbed dose rates is given as [14].

$$D = 0.461C_{Ra} + 0.623C_{Th} + 0.0414C_K$$

In the above conversions, it is assumed that all the decay products of ^{226}Ra and ^{232}Th are in radioactive equilibrium with their precursors. The mean air absorbed dose rate are 35.34, 25.76, 27.44, 42.41 nGyhr^{-1} for forest, flats, slopes, and catchments areas respectively.

Annual Effective Dose

To estimate the annual effective dose, account must be taken of to the conversion coefficient from absorbed dose in air to effective dose and the indoor occupancy factor. Using the dose rate data obtained from the concentration values of natural radionuclides in soil, adopting the conversion factor of 0.7 Sv/Gy absorbed dose in air to effective dose received by adults and considering that people on the average, spent 20% of their time outdoors, the annual effective doses are calculated [15]. The mean annual effective doses are 1.19 x 10^{-7}, 0.78 x 10^{-7}, 0.88 x 10^{-7}, 1.42 x 10^{-7} Sv for forest, flats, slopes, and catchment areas respectively.

External Hazard Index (H_{ex}) is defined as;

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_K/4810$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bqkg^{-1}, respectively . The value of this index must be less than unity in order to keep the radiation hazard to be insignificant. This is the radiation exposure due to the radioactivity from a construction material, limited to 1.5 mGyyr^{-1}. The maximum values of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (370 Bqkg^{-1}) [16].

The mean external radiation hazard index H_{ex} are 0.21, 0.16, 0.17, and 0.25 for forest, flats, slopes, and catchment areas respectively. The mean air absorbed dose rate is lower than the UNCEAR value i.e. 92 nGyyr^{-1}. The mean annual effective dose is also lower than the UNCEAR value i.e. 0.07 mSv. The external radiation hazard index is less then 1, which means it is safe for human to carry out their activities in the area.

Table 3: Air absorbed dose rate, external hazard index and annual effective dose for forest area

Code Sample	Absorbed dose rate (nGy/hr)				External hazard index (H_{ex})	Annual effective dose (10^{-7}Sv)
	^{40}K	^{226}Ra	^{228}Ra	Total		
			Forest area			
F_RSP_1	1.91	7.81	22.41	32.13	0.20	1.08
F_RSP_2	9.07	8.45	16.13	33.66	0.20	1.13
F_RSP_3	2.31	5.82	17.40	25.52	0.16	0.86
F_RSP_4	5.20	11.00	19.03	35.23	0.21	1.18
F_RSP_5	3.74	10.63	25.37	39.73	0.24	1.34
F_RSP_6	6.36	11.64	20.48	38.47	0.23	1.29
F_RSP_7	9.78	11.23	21.26	42.27	0.25	1.42
F_RSP_8	3.63	10.63	21.44	35.70	0.22	1.20
Range	1.91 - 9.78	5.82 - 1.64	16.13 - 25.37	25.52 - 42.27	0.20 - 0.25	0.86 - 1.19
Mean	5.25	9.65	20.44	35.34	0.21	1.19
			Flat area			
F_1CLSP_1	1.91	4.85	9.85	16.61	0.10	0.59
F_1CLSP_2	2.85	9.15	15.04	27.04	0.16	0.91
F_1CLSP_3	1.89	4.67	7.25	13.81	0.08	0.50
F_1CLSP_4	2.58	8.87	15.76	27.21	0.17	0.91
F_1CLSP_5	1.93	4.94	9.54	16.42	0.10	0.55
F_1CLSP_6	6.53	13.54	23.62	43.68	0.26	1.47
F_2CLSP_1	1.87	7.53	18.00	27.40	0.17	0.92
F_2CLSP_2	1.76	5.82	12.62	20.20	0.12	0.68
F_2CLSP_3	3.50	6.79	16.85	27.15	0.16	0.91
F_2CLSP_4	1.93	8.82	17.58	28.33	0.17	0.95
F_2CLSP_5	2.50	7.44	13.11	23.04	0.14	0.77
F_2CLSP_6	1.00	14.60	20.54	36.13	0.22	0.12
F_7CLSP_7	4.10	7.76	18.00	29.86	0.18	1.00
F_2CLSP_8	1.24	7.02	13.71	21.98	0.13	0.74
F_2CLSP_9	2.92	8.73	15.89	27.54	0.17	0.92
Range	1.00 - 6.53	4.85 - 4.60	9.54 - 23.62	13.81 - 36.13	0.10 - 0.26	0.50 - 0.80
Mean	2.57	8.04	15.16	25.76	0.16	0.78
			Slope area			
S_1CLSP_1	2.10	10.86	19.81	32.77	0.20	1.10
S_1CLSP_2	2.91	14.00	16.61	33.52	0.20	1.13
S_1CLSP_3	2.14	10.26	25.85	38.24	0.24	1.28
S_1CLSP_4	2.08	9.52	19.81	31.41	0.19	1.06
S_1CLSP_5	4.52	9.84	15.52	29.88	0.18	1.00
S_1CLSP_6	4.52	9.79	15.46	29.78	0.18	1.00
S_1CLSP_7	2.04	7.30	13.29	22.63	0.14	0.76
S_1CLSP_8	2.96	7.67	10.63	21.26	0.13	0.71
S_1CLSP_9	2.17	7.53	15.22	24.92	0.15	0.83
S_1CLSP_{10}	4.27	16.86	24.95	46.07	0.28	1.55
S_1CLSP_{11}	0.47	6.84	12.08	19.39	0.12	0.65
S_1CLSP_{12}	2.16	5.22	10.75	18.13	0.11	0.61
S_1CLSP_{13}	1.45	5.41	11.42	18.27	0.11	0.61
S_1CLSP_{14}	2.11	9.06	17.58	28.74	0.18	0.97
S_2CLSP_1	2.17	6.47	13.77	22.41	0.14	0.75
S_2CLSP_2	3.27	8.64	16.61	28.51	0.17	0.96
S_2CLSP_3	5.27	8.64	11.29	25.21	0.15	0.84
S_2CLSP_4	3.02	7.62	9.97	20.61	0.12	0.69
S_2CLSP_5	0.59	8.32	17.27	26.18	0.16	0.88
S_2CLSP_6	2.46	16.31	23.07	41.85	0.26	1.41
S_2CLSP_7	1.33	4.85	6.89	13.07	0.08	0.44
S_2CLSP_8	2.52	8.73	19.63	30.88	0.19	1.04
Range	0.47 - 5.27	4.85 - 6.86	6.89 - 25.85	18.13 - 46.07	0.11 - 0.28	0.44 - 0.92
Mean	2.57	9.08	15.79	27.44	0.17	0.88
			Catchments area			
$W1_1CLSP_1$	10.78	7.48	21.44	39.71	0.23	1.33
W_1CLSP_2	12.52	7.48	23.50	43.50	0.26	1.46
W_1CLSP_3	16.00	9.10	21.86	46.97	0.27	1.58
W_1CLSP_4	6.90	7.48	16.49	30.87	0.18	1.04
W_1CLSP_5	4.47	19.40	27.12	50.99	0.31	1.71
Range	6.90 - 6.00	7.48 - 9.40	16.49 - 27.12	30.87 - 46-.97	0.18 - 0.27	1.04 - 1.58
Mean	10.13	10.19	22.08	42.41	0.25	1.42

Figure 3 below shows the surface dose rate in uSvhr^{-1}, annual effective dose ($\times 10^{-7}$) in Sv, absorbed dose rate in uSv/hr, and external hazard index. The is a common trend where the highest values are from the catchments area.

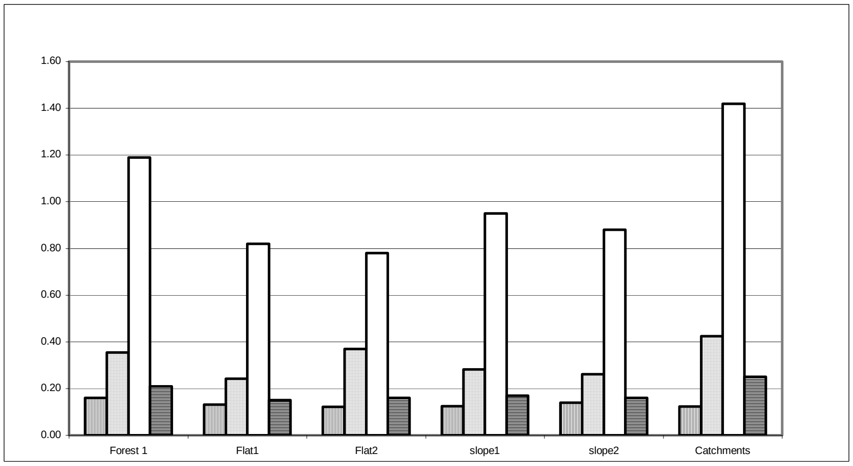

Figure 3. Surface dose rate ▥ annual effective dose ☐ , absorbed dose rate, ▒ and external hazards index, ▤ for various sections in the study area.

In short, the activity concentrations of natural radionuclides in top soil, ^{40}K, ^{226}Ra and ^{228}Ra vary in a different sections in the study area depending on the condition of the surface area of the soils. The amount of rain in the area influences very much the movement of these radionuclides which finally settles down in the catchment area. The trend shows in Figure 3 supported this statement.

Conclusion

From this study, the mean value of air absorbed dose and annual effective dose are lower than UNCEAR values. The external radiation hazard index is less than 1. These are an indication that the area is safe for the human activity.

Acknowledgement

The authors wish to thank the Universiti Teknologi Mara (UiTM) for financing this project through BRC Grant No 600-BRC/ST.5/3/599, and special thanks are also extended to Tuan Haji Ismail (land owner), Encik Zahir, Encik Din (both from UiTM Jengka); Cik Zalina Laili and Puan Rusni Rejab (both are from MINT) for their assistance.

References

1. Radiation Information Network Michigan University 2000. Radioactivity in nature, Retrieved May 30, 2005 from http://www.physics.isu.edu/radinf/natural.html
2. Tzortzis M., Svoukis E. & Tsertos H. 2001. A comprehensive study of natural gamma radioactivity levels and associated dose rates from surface soils in cyprus. *J. Radiant Prot Dosim*. 109: 217-224.
3. United Nations Scientific Committee of the Effect of Atomic Radiation (UNSCEAR) 2000. Sources and Effects of Ionizing Radiation. *Report on General Assembly, United Nations New York.*
4. Moore, W.S., Krishnaswami,S. 1972. Thorium: element and geochemistry. *The Encyclopedia of Earth Sciences Series*, Vol. IVA: 1183-1189
5. Haglund D.S. 2004. Uranium: element and geochemistry. The Encyclopedia of Earth Sciences Series, Vol. IVA: 1215 – 1222.
6. Brookins D.G. 1984. Geochemical, aspects of radioactive waste disposal, *Springer-Verlag, Berlin*, 23-27.
   United Nations Scientific Committee on the Effects of Atomic Radiation (UNCEAR) 1998. Sources, effects and risks of ionizing radiation, *Report, UN, New York.*
7. Standard Operating Procedure to surface and subsurface soil sampling. FSSO 002.00 (California SOP) 1999.
9. Faure G. 1986. Principles of Isotopes Geology. (2nd ed.): John Wiley & Son.

10. Menager M. T, Health M. J, Ivanovich M, Montjotin C., Barillon C. R, Camp J., Hasler SE. 1993. Migration of uranium-mineralised fractures into the rock matrix in granite: implications for radionuclide transport around a radioactive waste repository, *Radiochimica Acta* 66(7): 44-83.
11. Kocher, D.C., & Sjoreen, A.L. 1985. Dose-rate conversion factors for external exposure to photon emitters in soil. *Health Physics* 48: 193-205.
12. Jacob, P., Paretzke, H. G.,Rosenbaum, H., Zanki, M. 1986. Effective dose equivalents for photon exposure from plane sources on the ground. *Radiant. Prot. Dosim.* 14: 299-310.
13. Leung, K.C., Lau, S.Y., Poon, C.B. 1990. Gamma radiation dose from radionuclides in Hong Kong soil. *J. Environ. Radioactive* 11: 279-290
14. United Nations Scientific Committee on the Effects of Atomic Radiation (UNCEAR) 1993. Sources, effects and risks of ionizing radiation. *Report, UN, New York.*
15. Human Health Fact Sheet 2001. Potassium-40. Retrieved December 11, 2004 from http://www.oversight.state:id/or-library/contaminat-Fact-sheets/potassium.
16. Beretka, J., & Mathew, P.J. 1995. Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health Physics* 48: 87-95.