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Assessment of Radiation Dose Rates in the High Terrestrial Gamma Radiation Area of Selama District, Perak, Malaysia

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Abstract

Survey of terrestrial gamma radiation (TGR) dose rates have been conducted in Selama district, Perak, Malaysia. The mean value of TGR dose rate outdoor in Selama is (273 ± 133) nGy h^{-1}. For the habited land, the mean TGR dose rates outdoor and indoor are (205 ± 59) nGy h^{-1} and (212± 64) nGy h^{-1} respectively. They contribute fatal cancer risk of 6.4 x 10^{-5} per year to an individual in the area. The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in the soil samples were analysed using a high resolution co-axial HPGe gamma ray spectrometer system. The values obtained range from 57 Bq kg^{-1} to 364 Bq kg^{-1} with the mean value of (178±95) Bq kg^{-1} for ^{238}U; 207 Bq kg^{-1} to 625 Bq kg^{-1} with the mean value of (353±143) Bq kg^{-1} for ^{232}Th, and 26 Bq kg^{-1} to 601 Bq kg^{-1} with the mean values of (273±133) Bq kg^{-1} for ^{40}K.

Keywords: TGR dose rate, ^{238}U, ^{232}Th, ^{40}K, radiation risk

1. Introduction

Naturally occurring radioactive materials (NORM) existing in soil could pose potential health physics risk (Wilson, 1993), especially if assisted by natural processes such as weathering deposition and wind erosion (Elles et al., 1997). The radiological impact of NORM to the human populations is due to terrestrial gamma radiation, inhalation of air contaminated with radon gas and other radionuclide particulate, consumption of the agricultural products, water and their products (Kryshev et al., 1996). The terrestrial gamma radiation dose rate is influenced by soil types, geological features and geographical condition (Florou & Kritidis., 1992; Ramli, 1997). Human beings are exposed outdoors to the natural terrestrial radiation that originates predominantly from the upper 30 cm of the soil (Narayana et al., 1994). The high terrestrial gamma radiation dose rates are mostly found in areas with soils originating from granitic rocks (Kogan et al., 1969). The concentration of uranium and thorium in the soil in the area is also high. The world average values for terrestrial gamma radiation dose rates outdoor for the world and Malaysia are 57 nGy h^{-1} and 75 nGy h^{-1} respectively (UNSCEAR, 2000). The highest concentrations of radioactive minerals in soil are found in Brazil (Radhakrishna et al., 1993).

Selama has an area of 746 km^2 and population of about 36 405 (Selama District Council, 2009). It is one of 10 districts of Perak state. Its capital is also called Selama. It is located between the latitudes 5^{o}05' to 5^{o}26' North, and the longitudes 100^{o}37' to 100^{o}57' East. It is bordered on the north by Kedah State, on the east by Hulu Perak district, on the south by Larut Matang district and to the west by Kerian district. 66 % of the district is covered by forest (hills, mountains) and the main land use is for agriculture. The climate is tropical with temperature between 28^{o}C to 32^{o}C. Selama can be divided into four major geological groups of different geological ages (Director General of Geological Survey, 1985) as shown in Figure 1, that are Quaternary (mainly recent alluvium), Triassic-Jurassic (sediments rocks with conglomerates), Silurian (sediments rocks with associated lava and tuff), and acid and undifferentiated (granitic rocks). Granite based geological features is most abundant in Selama, it cover about 75 % of the area, and followed by Silurian (12 %), Triassic (9%), and Quaternary (4%). Selama is overlaid by five types of soil as classified by FAO /UNESCO (Director General of Agriculture Peninsular Malaysia, 1973). The soil types present according to FAO/UNESCO classification are Haplic Acrisol (locally are refered as Holyrood, Harimau), Dystric Fluvisol-Haplic Arenosol-Dystric Cabisol (Aluvium Tempatan- Telemong-Akob), Haplic Acrisol-Ferric Acrisol (Rengam-Bukit Temiang), Haplic Acrisol-Haplic Ferralsol (Serdang-Munchong) and steep land (miscellaneous soils). Soil types in Selama are shown in Figure 2.

The results obtained for this area can be used to determine the natural radiological background and can be used as one of the baseline data in the assessments of the environmental impacts of *amang* deposits and nuclear accidents.

2. Materials and Methods

2.1 Terrestrial gamma radiation (TGR) dose rates

The terrestrial gamma radiation dose rate was measured 1 meter above the ground by using two identical gamma-ray detectors and the average value was recorded. The detector used was model 19, micro roentgen (μR) meter, manufactured by Ludlum, USA. It uses 1″ × 1″ (2.54 × 2.54 cm^2) sodium iodide (NaI) crystal doped with thallium (Tl). The instrument was calibrated by Malaysia Nuclear Agency, it is a Secondary Standard Dosimetry Laboratory (SSDL). The terrestrial gamma radiation (TGR) dose rates were measured from locations with different soil types and geological backgrounds randomly, the results of TGR dose rate measurements are presented as an isodose contour map. The isodose map was drawn by using software surfer and modified according to soil type, geological background, and topological information. It is shown in Figure 3.

2.2 Concentration of ^{238}U, ^{232}Th and ^{40}K in soil samples

Soil samples were collected from locations with different terrestrial gamma radiation dose rates, soil types and geological features. All samples were dried by placing them in an oven at 110^{o}C for 24 hours then crushed and ground to fine powder by using a grinding mill (Herzog-D4500/type HSM 100, No. 62B/529, German-made). The samples were sieved by passing through a 200 mm test sieve/150 microns to be homogenized in size. Samples were sealed in plastic containers and left for at least one month, before gamma spectrometric analysis, to ensure secular equilibrium (Mollah et al.,1987; Ibrahim et al., 1993). The specific activity in soil (in Bq kg^{-1}) due to radionuclide *i* and for a peak at energy *E*, is given by Equation (1) (IAEA 1989),

$$A_{Ei} = \frac{N_{Ei}}{\varepsilon_{Ei}\, t\, \gamma_{Ei}\, M} \tag{1}$$

where N_{Ei} is the net peak area at energy E_i of radionuclide i, ε_{Ei} is the detection efficiency at energy E, t is the counting time, γ_{Ei} is the number of gammas per nuclear transformation of the radionuclide at energy E, and M is the mass in *kg* of the measured sample. The minimum detectable activity for counting time 10,800 s were estimated to be 4 Bq kg^{-1}, 9 Bq kg^{-1} and 19 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively.

Gamma ray spectrometric analysis of radionuclides were carried out by using a coaxial high purity germanium (HPGe) detector. The concentration of the radionuclide considered was determined from the peaks at 239 keV (^{212}Pb), 583 keV (^{208}Tl) and 911 keV (^{228}Ac) for ^{232}Th, the peaks at 352 keV (^{214}Pb) and 609 keV (^{214}Bi) for the ^{238}U and the peak at 1 460 keV for ^{40}K. The standard samples IAEA SL-14 and IAEA SL- 2 were used as reference materials and were mixed with SiO_2 in Marinelli beakers. For calibration, the IAEA reference materials ^{133}Ba, ^{22}Na, ^{137}Cs, ^{60}Co and ^{152}Eu, were used. To determine the detection efficiency of gamma energies from 200 keV to 2000 keV, Equation (2) was used,

$$Ln\, \varepsilon = 1.09 - 0.79\, Ln\, E \tag{2}$$

where ε is the detection efficiency and E is the gamma ray energy in keV. The minimum detectable activity for counting time of 10 800 s were estimated to be 4 Bq kg^{-1}, 9 Bq kg^{-1} and 19 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively.

3. Results and discussion

The mean value of terrestrial gamma radiation dose rates in Selama and other areas in Malaysia and the world are

presented in Table 1. The value of terrestrial gamma radiation dose rates measured from the 140 outdoor locations, ranged from 64 nGy h^{-1} to 715 nGy h^{-1}, with the mean value of (273 ± 133) nGy h^{-1}. This value is higher than the world and the Malaysian average as reported by UNSCEAR 2000. The mean TGR dose rate value in this area is higher than other areas of Perak, except for the area of Kg. Sg. Durian (Ramli et al., 2009, in communication). For the habited land in Selama, the mean TGR outdoor dose rate value is (205 ± 59) nGy h^{-1}. For the forested areas, the mean TGR dose rate outdoor is (351 ± 152) nGy h^{-1}.

TGR dose rates indoor for concrete houses in the high TGR dose rate areas were calculated using Equation (3) (Ramli, et al, 2009, in communication).

$$D_{in} = 0.33\ D_{out} + 144 \tag{3}$$

where D_{in} and D_{out} are TGR dose rate indoor and outdoor respectively. The indoor mean value for Selama district is estimated to be (212± 64) nGy h^{-1} for concrete houses.

The mean values of terrestrial gamma radiation dose rates for the five soil types and four geological backgrounds found in Selama are presented in Table 2. The steep lands and Haplic Acrisol-Ferric Acrisol (Rengam, Bukit Temiang) appear to have the higher mean TGR dose rates values. The steep lands mean value is (379 ± 143) nGy h^{-1} with values ranging from 234 nGy h^{-1} to 696 nGy h^{-1}, and the Haplic Acrisol-Ferric Acrisol mean value is (306 ± 161) nGy h^{-1} with values ranging from 64 nGy h^{-1} to 715 nGy h^{-1}. These soils were formed with granite as parent material. The highest mean TGR dose rate value based on geological background was found in acid undifferentiated areas. The mean value is (337 ± 16) nGy h^{-1} and ranged from 165 nGy h^{-1} to 715 nGy h^{-1}. The area are igneous acidic and extensively intruded by granitic rocks. The granite is relatively rich in radioactive minerals (UNSCEAR, 2000).

The mean values of ^{238}U, ^{232}Th and ^{40}K activity concentration in different soil samples are presented in Table 3. The activity concentration of the 15 soil samples for ^{238}U ranged from 57 Bq kg^{-1} to 364 Bq kg^{-1}, the mean value is (178 ± 95) Bq kg^{-1}; 207 Bq kg^{-1} to 625 Bq kg^{-1} for ^{232}Th, the mean value is (353 ± 143) Bq kg^{-1}; and 36 Bq kg^{-1} to 601 Bq kg^{-1} for ^{40}K, the mean value is (296 ± 184) Bq kg^{-1}. The average activity concentrations of ^{238}U and ^{232}Th in the soils of these areas are higher than the world average as reported in UNSCEAR 2000, but the activity concentration for ^{40}K is lower than world average value of 400 Bq kg^{-1}. The most abundant primordial radionuclide is thorium (^{232}Th). It is about 43% of the total (^{232}U + ^{232}Th + ^{40}K) . ^{238}U is 21% and ^{40}K is 36 %. The correlation between gamma dose rate *in situ* with the activity concentration of ^{232}U, ^{232}Th and ^{40}K in soil samples are given in Figure. 4.

Using the conversion coefficient factor for the absorbed dose in air to effective dose of 0.7 Sv Gy^{-1}, as recommended by UNSCEAR 2000 and the outdoor occupancy factor of 26% (Ramli et al., 2009, in communication), the annual effective dose (H_E) is calculated by using Equation (4),

$$H_E\,(\text{mSv y}^{-1}) = \text{Dose rate (nGy h}^{-1}\text{) x 24 hours x 365 days x } OF \text{ x 0.7 x 10-6} \tag{4}$$

where H_E is annual effective dose in mSv, and OF is occupancy factor that is 0.74 and 0.26 for indoor and outdoor respectively.

The average annual effective dose equivalent received in habited areas of Selama District are 0.96 mSv and 0.33 mSv for indoor (concrete houses) and outdoor respectively. The world annual effective dose equivalent average value are 0.41 mSv indoor and 0.07 mSv outdoor (UNSCEAR, 2000). The annual effective dose rate outdoor will be higher for steep lands, and areas with acid undifferentiated geological background; its mean value is 1.17 mSv. But these areas are not populated being mostly pristine jungle.

To estimate the fatal cancer risk to an individual $\hat{R}_i$, Equation (5) is used (Alvarez, 1997):

$$\hat{R}_i = a\sum H_E \quad , or \quad \hat{R}_i = a\,(H_{E\,in} + H_{Eout}) \tag{5}$$

where a is the risk factor, that is 0.05 death per sievert (ICRP 1990). H_{Ein} and H_{Eout} are effective dose rates indoor and outdoor respectively. The value of fatal cancer risk is about 6.4. x 10^{-5} per year to each individual living in habited land of Selama.

4. Conclusion

The mean terrestrial gamma radiation dose rate in Selama is about 3 times higher than the Malaysian average and about 5 times higher than the world average value. Eventhough the mean TGR dose rate is relatively high but the higher dose rate areas are mostly in unhabited areas, therefore the annual effective dose rate is less than the expected value based on the mean value for the Selama district. Nevertheless the average total fatal cancer risk of 6.4 x 10^{-5} per year to each individual in the Selama district is too small to cause alarm.

The higher values of terrestrial gamma radiation dose rate are associated with soils of granitic origin, which are Haplic Acrisol-Ferric Acrisol and steep land. These soils were formed with granite as parent material. The highest TGR dose

rate values based on geological background are found in acid undifferentiated (acid intrusive) areas, they are granitic. Granite is relatively rich in radioactive minerals. The most abundant radionuclide in the study areas is thorium-232.

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Table 1. TGR dose rate in Selama compared with the other parts of Malaysia and the world.

State/District in Malaysia	Mean ± Sd ($nGy\ h^{-1}$)	Range ($nGy\ h^{-1}$)	Reference
Selama district, Perak	273 ± 133	64 - 715	Present Study
Johor State	163 ± 122	9 - 1 262	Ramli et al., 2001
Melaka State	183 ± 54	54 - 378	Ramli et al., 2005
Kinta district, Perak	222 ± 191	39 - 1 039	Lee et al., 2009
Pontian district, Johor	67	50 - 230	Ramli, 1997
Kota Tinggi district, Johor	180 ± 20	9 - 1 262	Ramli et al., 2003
Ulu Tiram, Johor	200	98 - 409	Abdul Rahman, A.T. & Ramli, 2007
Kg Sungai durian, Perak	458 ± 295	78 - 1 039	Ramli et al., 2009
Malaysia	92	55 - 130	UNSCEAR, 2000
World	57	18 - 93	UNSCEAR, 2000

Table 2. Terrestrial gamma radiation dose rate from different soil types and geological background in Selama, Perak

Soil type and Geological background	N sample	Mean ($nGy\ h^{-1}$)	Std Dev	95% Confidence Interval for Mean		Min	Max
				Lower	Upper		
Soil types (FAO/UNESCO)							
Haplic Acrisol-Haplic Acrisol	23	241	63	213	268	129	357
Dystric fluvisol-Haplic Arenosol - Dystric Cabisol	30	220	46	203	237	123	311
Haplic Acrisol-Ferric Acrisol	46	306	161	259	354	64	715
Haplic Acrisol-Haplic Ferralsol	16	158	40	137	179	116	246
Steep land (Miscellaneous soils)	25	379	143	320	438	234	696
Geological background							
Acid and undifferentiated	78	337	143	304	369	165	715
Quaternary	12	155	38	131	179	121	233
Silurian	36	222	44	207	237	116	278
Triassic-Jurassic	14	152	59	118	186	64	311
Present study	140	273	133	251	295	64	715
Malaysian average (UNSCEAR 2000)		92					
World average (UNSCEAR 2000)		57					

Table 3. Concentration of ^{238}U, ^{232}Th and ^{40}K in soil sample and the corresponding TGR dose rate in air 1 m above the ground

Soil sample	Soil Types (FAO/UNESCO)	Geological Background	Concentration (Bq kg^{-1})			TGR dose rate at The point sampling
			^{238}U	^{232}Th	^{40}K	
S 1	Haplic Acrisol-Haplic Acrisol	Quartenary	126	252	290	260
S 2	Haplic Acrisol-Haplic Acrisol	Acid undifferentiated	117	625	60	330
S 3	Dystric Fluvisol-Haplic Arenosol - Dystric Cabisol	Silurian	139	272	291	273
S 4	Haplic Acrisol-Ferric Acrisol	Triassic-Jurassic	57	207	198	130
S 5	Haplic Acrisol-Ferric Acrisol	Triassic-Jurassic	65	384	215	142
S 6	Haplic Acrisol-Ferric Acrisol	Acid undifferentiated	158	459	378	390
S 7	Haplic Acrisol-Ferric Acrisol	Acid undifferentiated	152	245	251	260
S 8	Haplic Acrisol-Ferric Acrisol	Acid undifferentiated	140	211	464	234
S 9	Haplic Acrisol-Ferric Acrisol	Acid undifferentiated	206	507	104	429
S 10	Haplic Acrisol-Ferric Acrisol	Acid undifferentiated	166	247	579	311
S 11	Haplic Acrisol-Ferric Acrisol	Acid undifferentiated	247	276	439	364
S 12	Haplic Acrisol-Ferric Acrisol	Acid undifferentiated	364	521	36	520
S 13	Steep land	Acid undifferentiated	286	566	78	559
S 14	Haplic Acrisol-Haplic Ferralsol	Acid undifferentiated	357	297	601	325
S 15	Dystric Fluvisol-Haplic Arenosol - Dystric Cabisol	Silurian	96	224	455	273
Present Study			178 ± 95	353 ± 143	296 ± 184	273 ± 133
Malaysia average (UNSCEAR, 2000)			66 (49-86)	82 (63-110)	310 (170-430)	92 (55-130)
World average (UNSCEAR, 2000)			35 (16-110)	30 (11-64)	400 (140-850)	57 (18-93)

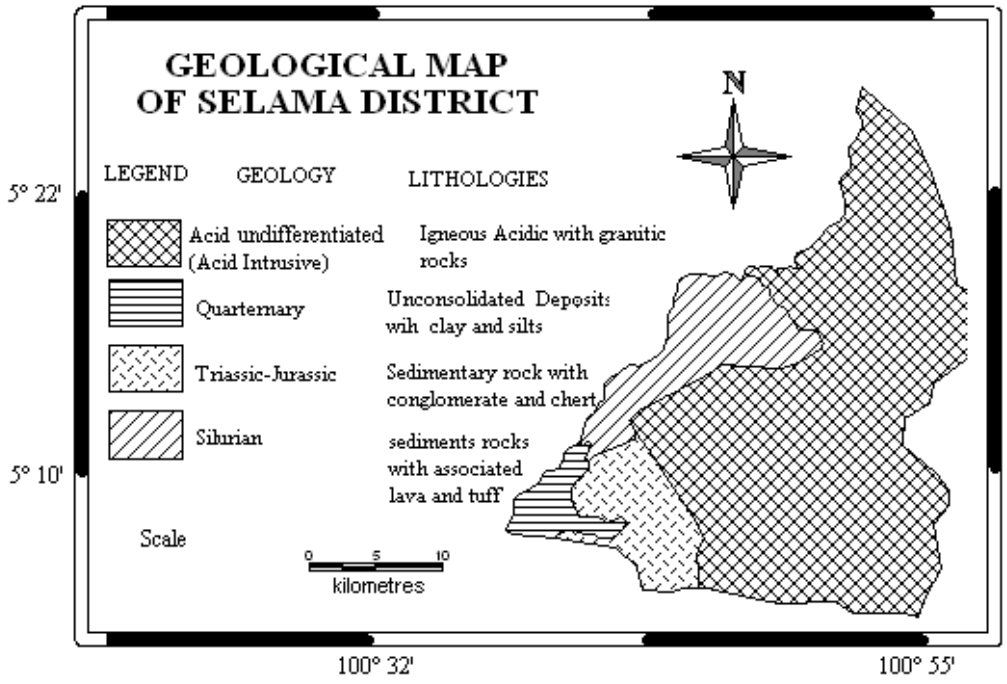

Figure 1. Map of geological features and its lithologies in Selama district, Perak, Malaysia (Director General of Geological Survey 1985)

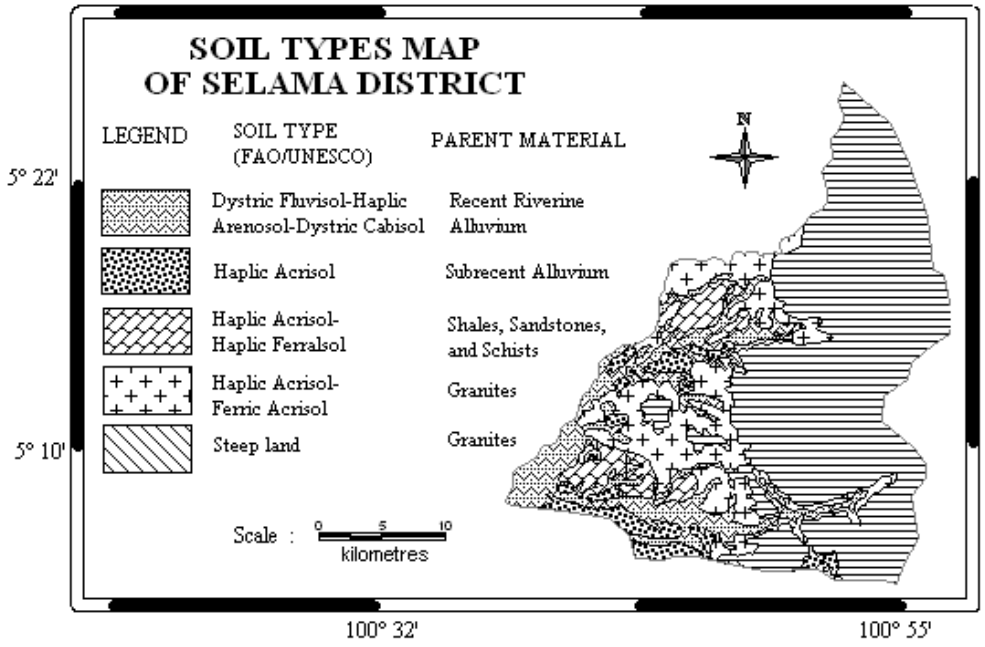

Figure 2. Map of soil types and its parent materials in Selama district, Perak, Malaysia (Directorate of National Mapping Malaysia, 1970).

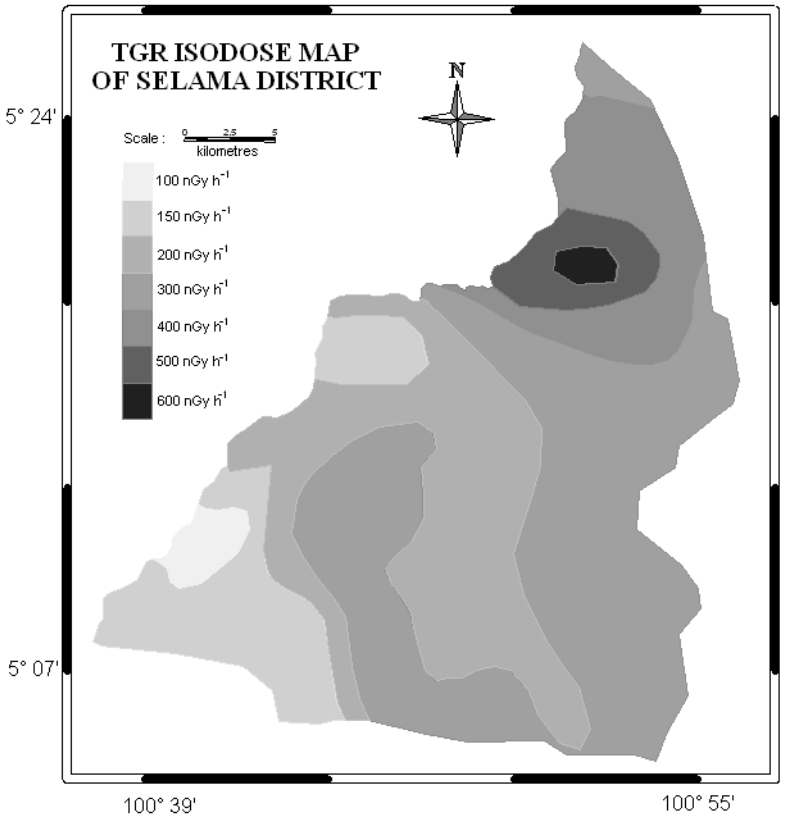

Figure 3. Map of terrestrial gamma radiation dose rates (nGy h^{-1}) in Selama District, Perak, Malaysia

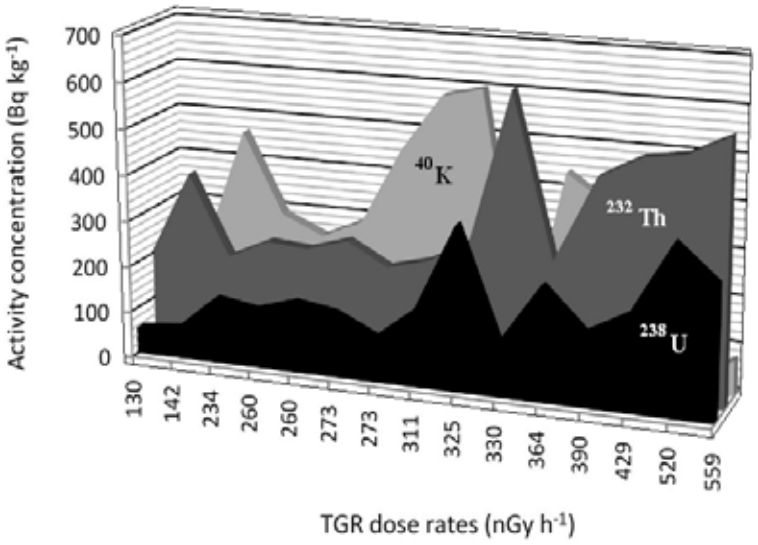

Figure 4. The TGR dose rate versus activity concentration of ^{238}U, ^{232}Th, and ^{40}K in soil samples