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Natural radioactivity and radiological hazard evaluation in surface soils at the residential area within Ban Gie monazite placer, Nghe An

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Abstract

^{226}Ra, ^{238}U, ^{232}Th(^{228}Ra), and ^{40}K activities of 51 surface soils samples at Ban Gie monazite placer, Vietnam were measured by HPGe detector. The highest activity was found for ^{40}K, followed by ^{232}Th, ^{226}Ra, and ^{238}U. The result showed insignificant difference between in and close to ore body of ^{226}Ra, ^{238}U activities while the significant difference between ^{232}Th and ^{40}K concentration in and close to the ore body was observed. There were disequilibrium between ^{238}U and ^{226}Ra, and the strongest positive correlation was found between ^{232}Th and Ra_{eq}. The Ra_{eq}, D, AEDE and ELCR indexes both in and close ore body exceed the global average values, except for ^{40}K.

Keywords Natural radionuclides · Radiological hazards · Monazite placer · Surface soil · Ban Gie · High radioactivity

Introduction

Determination of ^{226}Ra, ^{238}U, ^{232}Th, ^{40}K activity concentration in topsoil and rock plays an important role in the evaluation of the outdoor terrestrial natural radiation [1–3]. Thus, the activity concentration of these natural radionuclides and its radiological hazards in rock and topsoil (a product of rock weathering) have been widely measured and estimated around the world, especially in and surrounding high-level radioactivity and residential areas [4–15]. In general, these previous studies showed that the natural radionuclide concentration significantly depended on the types of soil and magma rock, geological formation. Radionuclide bearing minerals in the weathering layer, young sediment, and the feature of the ore deposits varies from place to place [15–20]. Therefore, the evaluation of natural radionuclide concentration in soil and rock in a specific area is very useful in order to provide the baseline data and to estimate the radiation hazards to human health.

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In Vietnam, the natural radionuclides in topsoil in densely populated areas or surrounding high-level radioactivity areas have been recently investigated [7, 19, 20]. The research results of Huy et al., 2012 [20] showed that the average concentration of natural radionuclides in surface soils in 63 provinces of Vietnam was 43 ± 18 Bq/kg, 60 ± 20 Bq/kg, and 412 ± 230 Bg/kg for ^{226}Ra, ^{232}Th, and ^{40}K respectively. Recently, Ba et al. (2019) [19] reported that the average ^{232}Th, ^{238}U, and ^{40}K activities in surface soil samples at district 1, Ho Chi Minh city, Vietnam were 25 ± 2, 33 ± 1, and 215 ± 7 Bg/kg respectively. It could be seen that the average concentrations of natural radionuclides in soil samples in Ho Chi Minh City were lower than their average values in soil samples in Vietnam. For surface soil samples in and surrounding the rare earth element mine in Muong Hum, Lao Cai, Vietnam, the average activity concentration of ^{226}Ra, ^{238}U, ^{40}K, and ^{232}Th was 156, 254, 647, and 908 Bq/kg, respectively [7]. These values were significantly higher than the average values of natural radionuclide concentration in soil samples in Vietnam. This indicates that although the average values of concentration of natural radionuclides in surface soil samples in Vietnam have been reported, the concentration of natural radionuclides in a specific area needs to be extensively investigated, especially in and surrounding the placer such as monazite placer with a high level of radiation.

In this study, the natural radionuclide activities and radiological hazards in surface soil (topsoil) at the residential area in and close a monazite placer in Ban Gie, Nghe An, Vietnam will be investigated. The location of the monazite placer was shown in Fig. 1. As reported in the previous literature, the natural radionuclide in monazite placer has been widely evaluated. Accordingly, many places in the world were rich in monazites and known as high background radiation areas, such as Odisha coastal area in eastern India [21], Kerala coastal in India [22], Ullal region in India [23], south Madagascar [11, 13]. In addition, the monazite placer often contains a high concentration of thorium (^{232}Th) which is one of the natural radionuclide decay chains with strong gamma emission. In Ban Gie monazite placer, many people are living in and close to this area. There was rarely studies which reported of natural radionuclide activities and radiological hazard assessment for resident living in and surrounding monazite placers in Vietnam. Thus, the evaluation of natural radionuclide activities and their radiation hazards to human health in this area is very important. The study also provides the baseline data to assess the radiation activity of Natural Occurring Radioactive Materials (NORM) as well as a reference for the reader from this study. A number of soil samples at the residential area in and close the placer were taken from fifty-one points for this investigation. The activity concentration of ^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K in studied samples were measured and used to estimate the radiological hazards, including radium equivalent activity (Ra_{eq}), absorbed gamma dose (D), annual effective dose equivalent (AEDE), and excess lifetime cancer risk (ELCR).

Sample preparation and methods

Topsoil samples were taken from fifty-one points in the dry season of 2019 at Ban Gie residential area in and close to the monazite placer (Fig. 1). Ban Gie monazite placer has coordinates 19°46′30″N, 105°29′50″W longitude in Yen Hop commune, Quy Hop district, in the west of Nghe An province, 130 km from Vinh city. As seen in this Fig. 1, the geological feature of this mine includes three formations: Bu Khang formation (*PR_3-$\varepsilon_1$bk*), Song Ca formation (*O_3-S_1sc*), and Dong Do formation (*T_3n-r đđ*). Monazite ore bodies are distributed in valleys with an area from 550,000

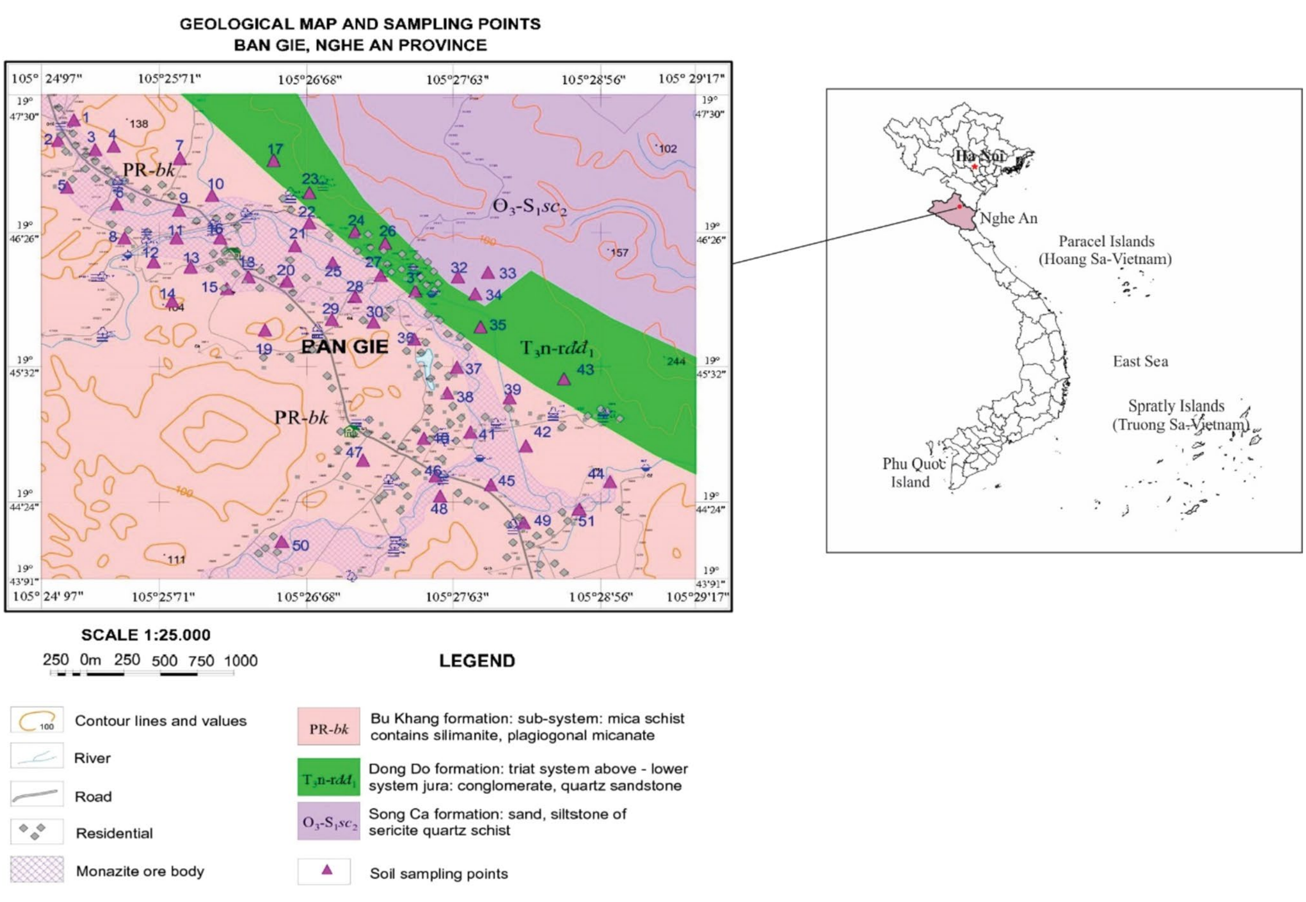

Fig. 1 Studied location and sampling points

to 1,100,000 m^2, with reserves of 190,360 tons of monazite; 826,990 tons of ilmenite; 332,670 tons of zircon. The mineral composition includes monazite, ilmenite, xenotin, zircon, rutile and silver. The chemical composition includes monazite from 150 to 4800 g/m^3; ilmenite from 200 to 2734 g/m3; zircon from 29 to 143 g/m^3; Ag = 167 g/m^3; U_3O_8 from 0.055 to 0.087%; ThO_2 from 4.62 to 6.61%.

The preparation of soil samples was conducted similarly to some previous studies [7, 11, 12]. Accordingly, the gravel, rock fragments, and tree roots in the soil samples were removed by hand. The soil samples were then dried at 110 °C temperature in an electric oven to a constant weight. The dry samples were ground and sieved pass through the sieve less than 2 mm in size. The fine soil sample was taken to weight, then put into a cylindrical plastic box and sealed for 30 days to reach a secular equilibrium between the radium and its daughter radionuclides.

To measure the radionuclide activities, MDA, calibration procedures, a high-resolution HPGe detector which were shown in previous studies [7, 8, 12, 24, 25] and employed for this study. The Gamma Vision software was used to analyze the spectrum. The activity concentration of each natural radionuclide was calculated from its respective gamma lines with the gamma lines of 609.3 keV, 1120.3 keV, and 1764.5 keV for ^{226}Ra, the gamma line of 1460 keV for ^{40}K. The lines of 911.2 keV, 969.0 keV, 2614.5 keV, 583.0 keV were used for ^{232}Th (^{228}Ra). The line of 1001 keV was used for ^{238}U (which was verified by ^{235}U measurement with 186 keV line). The ^{232}Th was mentioned and measured with the assumption of equilibrium between ^{232}Th and ^{228}Ra (^{228}Th) in soil samples [11, 26, 27].

The calculation of natural radionuclide activity concentrations, radiation hazard parameters, including Ra_{eq}, D, AEDE, and ELCR has followed the methods which was shown and represented in some previous studies [7, 8, 24, 27]. The Ra_{eq}, D, AEDE, and ELCR calculatal formulas were presented concise below:

Radium equivalent activity (Ra_{eq})

The Ra_{eq} was calculated based on the estimation of the same gamma ray dose rate for ^{226}Ra, ^{232}Th and ^{40}K.

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (1)$$

where A_{Ra}, A_{Th}, A_K are the ^{226}Ra, ^{232}Th and ^{40}K activities (Bq. kg^{-1}).

Absorbed gamma dose rate (D)

The *D* was used to evaluate the exposure and absorption of radiation to the human body at 1 m above the ground containing naturally occurring radionuclides [27]:

$$D\left(nGy \cdot h^{-1}\right) = 0.46A_{Ra} + 0.62A_{Th} + 0.042A_K \quad (2)$$

where A_{Ra}, A_{Th}, and A_K are of ^{226}Ra, ^{232}Th (^{228}Ra), and ^{40}K activity (Bq. kg^{-1}) respectively.

Annual effective dose equivalent (AEDE)

The outdoor annual effective dose equivalent (AEDE) was calculated as the following equation:

$$AEDE\left(Sv \cdot y^{-1}\right) = D\left(nGy \cdot h^{-1}\right) \times DCF\left(Sv \cdot Gy^{-1}\right) \times OF \times T \quad (3)$$

where *D* is the absorbed gamma dose rate; DCF is an outdoor dose convention factor (DCF = 0.7 Sv.Gy^{-1}); OF is an outdoor occupancy factor (OF = 0.2) [27]; T is the time factor (*T* = 8760 h).

Excess lifetime cancer risk (ELCR)

The excess lifetime cancer risks (ELCR) was calculated using the following equation:

$$ELCR = AEDE / Life\ Expectancy\ (LE) / Risk\ factor\ (RF) \quad (4)$$

where LE is the life expectancy of Vietnamese people is taken as 75.8 years [28]; RF is a fatal risk factor per Sievert which is equal to 0.057 Sv^{-1} [29].

Results and discussions

Activity concentration

The results of the activity concentration of natural radionuclides (^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K) were listed in Table 1. As shown in this table, the activity concentrations in surface soil samples vary from 11.9 ± 1.9 Bq/kg to 237 ± 9.1 Bq/kg (126 ± 5.2 Bq/kg on average), 16.4 ± 1.8 Bq/kg to 143 ± 7.5 Bq/kg (71 ± 5.6 Bq/kg on average), 22.9 ± 3.3 Bq/kg to 399 ± 12 Bg/kg (155 ± 7.5 Bg/kg on average), and 48.4 ± 2.9 Bq/kg to 1250 ± 100 Bg/kg (371 ± 22 Bq/kg on

Table 1 Activity concentration of studied natural radionuclides

Sample Nos	Location	Activity concentration (Bq/kg)				
		^{226}Ra	^{238}U	^{232}Th	^{40}K	^{238}U/^{226}Ra
1	Ore body	54.0 ± 4.8	32.0 ± 5.1	71.7 ± 4.4	109 ± 6.5	0.59
2	Close ore body	115 ± 7.2	65.7 ± 6.9	106 ± 6.6	237 ± 15	0.57
3	Ore body	118 ± 2.4	111 ± 6.3	230 ± 9.2	670 ± 47	0.94
4	Close ore body	124 ± 7.2	78.2 ± 8.4	180 ± 9.6	209 ± 10	0.63
5	Ore body	113 ± 4.8	91.5 ± 5.1	281 ± 5.4	212 ± 16	0.81
6	Ore body	116 ± 7.2	120 ± 9.9	165 ± 6.5	300 ± 17	1.0
7	Close ore body	112 ± 4.2	67.4 ± 4.7	105 ± 5.1	236 ± 10	0.60
8	Close ore body	162 ± 4.8	84.8 ± 6.6	162 ± 8.4	93.0 ± 6.4	0.52
9	Ore body	112 ± 5.6	55.1 ± 5.7	153 ± 5.8	195 ± 11	0.49
10	Ore body	177 ± 4.8	94.3 ± 5.1	215 ± 9.4	890 ± 54	0.53
11	Ore body	217 ± 6.2	105 ± 8.0	178 ± 8.3	620 ± 43	0.48
12	Close ore body	65.5 ± 2.4	33.6 ± 1.8	68.8 ± 6.6	550 ± 23	0.51
13	Ore body	205 ± 4.7	77.9 ± 5.0	237 ± 7.4	143 ± 9.1	0.38
14	Close ore body	199 ± 8.9	82.3 ± 9.7	233 ± 12	93.5 ± 6.5	0.41
15	Ore body	176 ± 6.5	106 ± 7.9	290 ± 9.3	145 ± 10	0.60
16	Ore body	216 ± 12	98.1 ± 9.2	261 ± 13	160 ± 7.4	0.45
17	Close ore body	11.9 ± 1.9	23.9 ± 3.2	35.4 ± 3.3	80.4 ± 5.4	2.0
18	Ore body	53.5 ± 2.4	27.8 ± 1.8	56.3 ± 4.9	153 ± 8.6	0.52
19	Close ore body	78.1 ± 4.7	39.3 ± 3.5	86.2 ± 5.8	71.8 ± 4.8	0.50
20	Ore body	230 ± 9.3	121 ± 8.4	374 ± 16	890 ± 62	0.53
21	Ore body	119 ± 7.1	57.8 ± 6.8	95.4 ± 6.5	1180 ± 48	0.49
22	Ore body	152 ± 7.1	70.5 ± 9.1	162 ± 8.7	520 ± 21.7	0.46
23	Close ore body	205 ± 2.4	96.1 ± 4.8	199 ± 9.6	1250 ± 100	0.47
24	Close ore body	204 ± 11	100 ± 5.5	122 ± 11	643 ± 35	0.49
25	Ore body	77.4 ± 2.4	41.6 ± 3.3	84.2 ± 4.2	69.1 ± 4.6	0.54
26	Close ore body	131 ± 2.4	62.2 ± 3.3	142 ± 5.3	311 ± 22	0.47
27	Ore body	59.5 ± 4.7	29.5 ± 3.5	75.1 ± 4.4	48.4 ± 2.9	0.50
28	Ore body	125 ± 4.7	72.3 ± 9.5	164 ± 8.4	611 ± 37	0.58
29	Close ore body	69.2 ± 2.4	31.6 ± 3.3	62.3 ± 5.7	67.7 ± 4.7	0.46
30	Close ore body	169 ± 7.1	70.7 ± 6.8	130 ± 6.5	511 ± 21	0.42
31	Ore body	179 ± 4.7	92.9 ± 6.5	205 ± 5.8	890 ± 70	0.52
32	Close ore body	105 ± 6.8	49.5 ± 6.6	121 ± 8.2	262 ± 15	0.47
33	Close ore body	45.6 ± 2.4	16.4 ± 1.8	22.9 ± 3.3	118 ± 5.7	0.36
34	Close ore body	124 ± 7.1	68.5 ± 5.3	137 ± 6.9	122 ± 8.8	0.55
35	Close ore body	138 ± 4.7	58.1 ± 6.5	107 ± 6.4	417 ± 23	0.42
36	Close ore body	87.8 ± 7.1	48.6 ± 6.8	76.7 ± 5.9	132 ± 8.4	0.55
37	Close ore body	109 ± 4.7	49.7 ± 5.0	83.9 ± 6.3	125 ± 8.8	0.46
38	Close ore body	223 ± 6.3	104 ± 7.7	197 ± 10	267 ± 12	0.47
39	Close ore body	49.4 ± 2.4	29.3 ± 3.3	42.4 ± 4.1	269 ± 17	0.59
40	Close ore body	53.6 ± 4.9	25.5 ± 5.2	44.7 ± 4.5	326 ± 23	0.48
41	Close ore body	39.2 ± 2.4	26.7 ± 1.8	39.3 ± 3.8	285 ± 12	0.68
42	Close ore body	133 ± 4.7	79.9 ± 5.0	130 ± 6.4	245 ± 19	0.60
43	Close ore body	222 ± 8.6	118 ± 6.5	228 ± 11	207 ± 12	0.53
44	Ore body	237 ± 9.1	117 ± 8.3	365 ± 15	756 ± 46	0.49
45	Ore body	76.5 ± 4.7	56.2 ± 3.5	210 ± 6.4	125 ± 8.8	0.73
46	Ore body	51.9 ± 2.4	30.3 ± 1.8	85.5 ± 4.3	351 ± 15	0.58
47	Close ore body	61.3 ± 2.4	48.6 ± 1.8	59.3 ± 4.7	55.9 ± 3.4	0.79
48	Ore body	140 ± 6.5	90.3 ± 7.9	209 ± 8.3	930 ± 49	0.65
49	Close ore body	85.3 ± 2.4	81.9 ± 4.8	43.8 ± 4.2	222 ± 14	0.96

Table 1 (continued)

Sample Nos	Location	Activity concentration (Bq/kg)				
		^{226}Ra	^{238}U	^{232}Th	^{40}K	^{238}U/^{226}Ra
50	Ore body	154 ± 4.5	138 ± 4.9	392 ± 17	790 ± 56	0.90
51	Ore body	148 ± 4.7	143 ± 7.5	399 ± 12	780 ± 32	0.97
Average		126	71	155	371	0.60
Min		11.9 ± 1.9	16.4 ± 1.8	22.9 ± 3.3	48.4 ± 2.9	0.36
Max		237 ± 9.1	143 ± 7.5	399 ± 12.0	1250 ± 100	2.0
Median		119	70.5	137	245	
Skewness		0.20	0.23	0.90	1.14	
Kurtosis		− 0.95	− 0.85	0.33	0.39	
SD		59.5	32.9	96.5	313	

average) for ^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K, respectively. The highest average concentration was found for ^{40}K, followed by ^{232}Th, ^{226}Ra, and ^{238}U. In general, the average concentrations of natural radionuclides ^{226}Ra, ^{238}U, and ^{232}Th were higher than their global average concentration values in soil which were 32 Bq/kg, 33 Bq/kg, and 45 Bq/kg for ^{226}Ra, ^{238}U, and ^{232}Th (^{228}Ra), respectively [27]. For ^{40}K, the average concentration in the study area was lower than the world average value (420 Bq/kg) [27]. The high concentration of natural radionuclides in monazite placer was also reported in the literature [11, 21–23]. The research results of this study also indicate that the highest variation of activity concentration in soil samples was observed for ^{40}K with the standard deviation (SD) of 313 Bg/kg. The wide variation of ^{40}K concentration was also found in soil samples close to the ore body in Muong Hum, Viet Nam [7]; in surface soil samples in Bolikhamxay, Laos [8]; in soil sample in Savannakhet, Laos [24]; in soil sample in Khammouan province, Laos [12]. The asymmetric distribution curve of natural radionuclides was plotted in Fig. 2. As shown in this Fig, the activity concentration of ^{226}Ra and ^{238}U in the study area (ore body and close ore body) were nearly normal distribution with the Skewness values of 0.20 and 0.23, respectively. This indicates that there was no significant difference in the concentration of ^{226}Ra, ^{238}U in and close the ore body. By contrast, the concentrations of ^{232}Th and ^{40}K were the right-skewed (positive skew) distribution with the Skewness values of 0.90 and 1.14, respectively. The right-skewed distribution of ^{40}K could be explained based on the high mobility of potassium and it was easily transported by water [30, 31].

As listed in Table 1, the ratio ^{238}U/^{226}Ra slightly ranged from 0.36 to 2.0 with an average value of 0.6. This result indicated the disequilibrium between ^{238}U and ^{226}Ra concentration. The phenomenon was also observed in the soil at monazite placer in Madagascar [11], rare earth element mine in Muong Hum [7], and in Penang (Malaysia) [32]. The difference in concentration of ^{238}U and ^{226}Ra in the soil could be attributed to the difference in the mobility of ^{238}U and ^{226}Ra [33, 34]. In addition, the differences in the geochemical properties of the uranium and radium elements could lead to the difference in concentration of ^{238}U and ^{226}Ra in soil [11].

The correlations among different natural radionuclides in the study area were shown in Fig. 3. There were the highest strong correlations between ^{232}Th and ^{238}U concentration (r = 0.86, $P < 0.001$), between ^{226}Ra and ^{238}U concentration (r = 0.81, $P < 0.001$). By contrast, a weak correlation was found between ^{226}Ra and ^{40}K concentration (r = 0.45, $P = 0.001$), between ^{232}Th and ^{40}K concentration (r = 0.44, $P = 0.001$). This result indicates that the ^{232}Th and ^{232}U radionuclides have the same origin (Veerasamy et al., 2020) [21] and there was significant independence between the two radionuclides [35]. The weak correlation between activity concentration of ^{232}Th and ^{40}K indicates that the ^{40}K activity does not relate to the presence of ^{232}Th bearing minerals and the result was well agreement with previous report in Prakash et al. (2018) [23].

The natural radionuclide concentration in the study soil samples was compared with other regions in Vietnam and the world (Table 2). In comparison with some other regions in Vietnam, the concentration of natural radionuclides in study soil samples were higher than that in soil in Ho Chi Minh city [19] and the average values in soil in 63 provinces of Vietnam [20]. By contrast, the activities values were significantly lower than those in REE mine in Muong Hum where was known as a high radioactivity area [7]. In comparison with other regions in the world, the natural radionuclide activities in study area were higher than that in some provinces of Laos, Turkey, southern Thailand, and Nigeria [8, 12, 24, 36–38]. Whereas it was lower than that in Penang

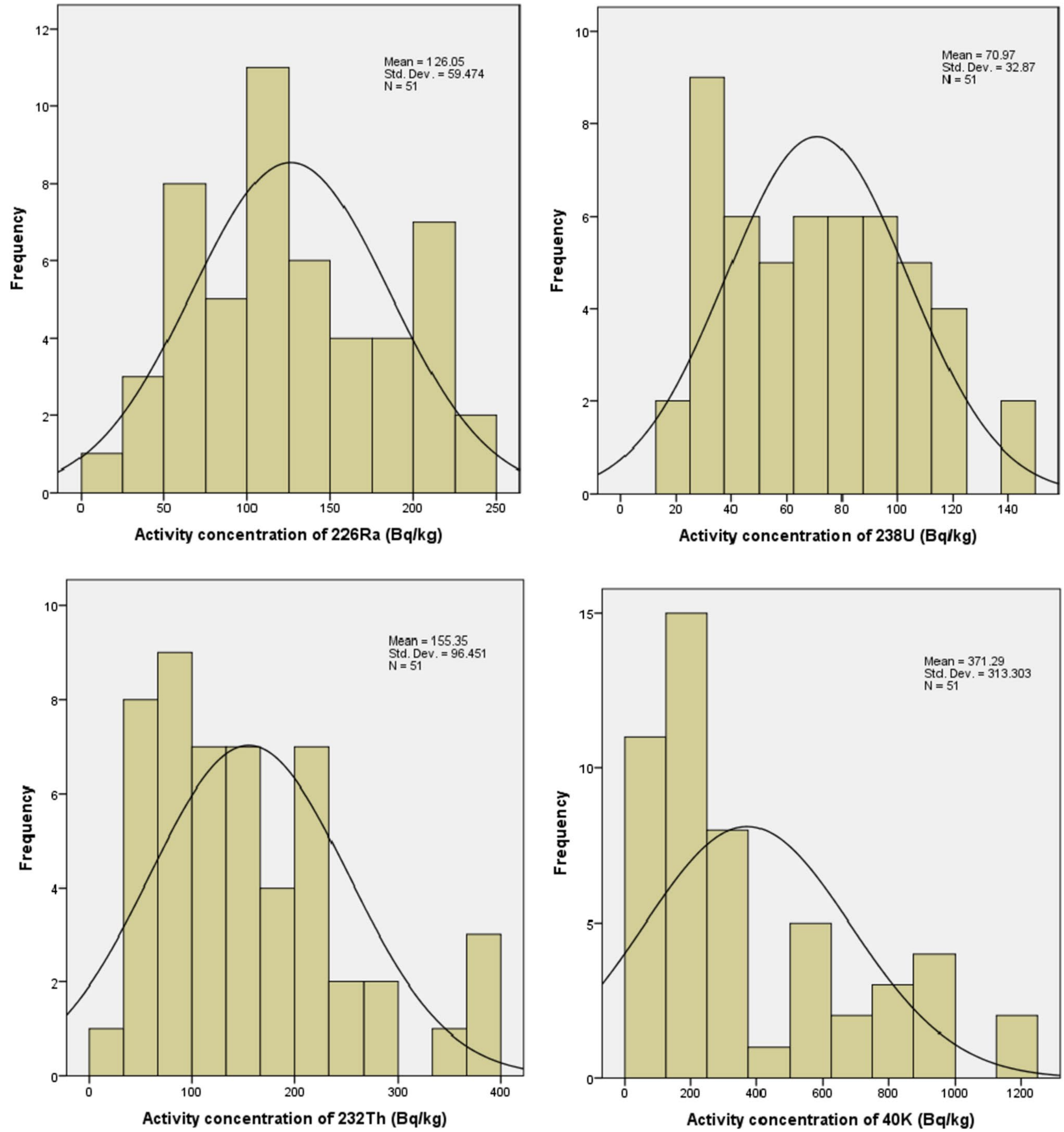

Fig. 2 Distribution curve of ^{226}Ra, ^{238}U, ^{232}Th (^{228}Ra), and ^{40}K concentration in the study area

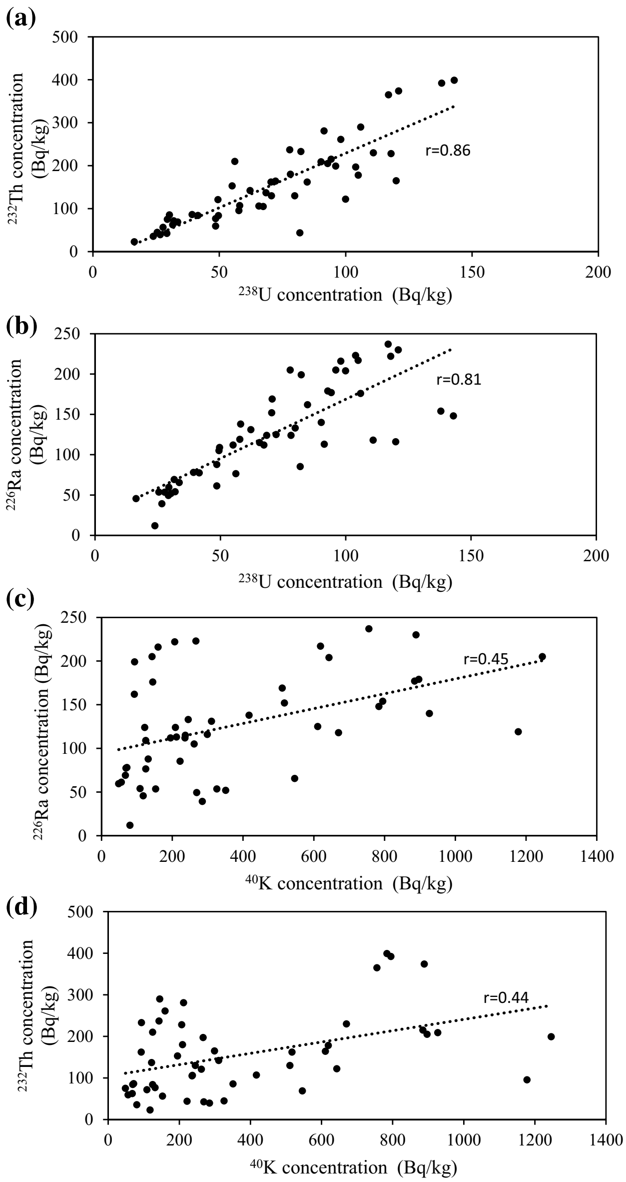

Fig. 3 Correlation among different radionuclides in the study area

(Malaysia) [32], far lower than Guangdong uranium mine in China [41] and almost similar in some provinces of Malaysia [39, 40]. In comparison with monazite placer types, the radionuclide activities of this study area were lower than those reported in some monazite placer mines in the world such as Kerala coast (India), Ullal coast (India), south Madagascar [11, 22, 23].

Figure 1 showed that people are living both in and close to the ore bodies. Thus, it is necessary to compare the activity concentration of natural radionuclides in and close the ore body. The variation of ^{226}Ra, ^{238}U, ^{232}Th, and ^{40}K in and close the ore body was shown in Figs. 4. Figures 4a, b showed that the concentration of ^{226}Ra varied from 51.9 to 237 Bg/kg (138 Bq/kg on average) and from 11.9 to 223 Bq/kg (116 Bq/kg on average) for soil in and close the ore body respectively. For ^{238}U (Fig. 4c, d), the activity concentration in and close the ore body ranged from 27.8 to 143 Bq/kg (82.5 Bq/kg on average), 16.4 Bg/kg to 118 Bq/kg (60.8 Bq/kg on average), respectively. In Fig. 4e, f, the concentration of ^{232}Th ranged from 56.3 to 399 Bq/kg (207 Bq/kg on average) in the ore body and from 22.9 to 233 Bq/kg (110 Bq/kg on average) close the ore body. As shown in Fig. 4e, f, the concentration of ^{40}K varied from 48.4 to 1180 Bq/kg with a mean value of 481 Bq/kg in the ore body and from 55.9 to 1250 Bq/kg with an average of 274 Bq/kg close the ore body. It could be seen that the differences in average activity concentration of ^{226}Ra, ^{238}U in and close the ore body were insignificant. By contrast, the average concentration of ^{232}Th in the ore body (207 Bg/kg) was almost two times higher than that close to the ore body (110 Bg/kg) (Fig. 4e, f). This phenomenon could be attributed to the feature of monazite deposit which is the main source of thorium. Similarly, the average concentration of ^{40}K in the ore body (481 Bg/kg) was about 1.8 times higher than that close to the ore body (274 Bg/kg) (Fig. 4g, h).

Radiological hazards

The calculated results of radiological hazard indices (Ra_{eq}, D, AEDE, ELCR) for the soil samples in the study area and the world average values were listed in Table 3.

As listed in Table 3, in the ore body, the Ra_{eq} varied from 146 to 833 Bq/kg with a mean of 470 Bq/kg while close the ore body, the Ra_{eq} were in the range from 68.7 to 586 Bq/kg with an average of 294 Bq/kg. It could be seen that the Ra_{eq} in the ore body was higher than the average world value (370 Bq/kg) while that close the ore body was lower than the average world value. The correlations between Ra_{eq} and

Table 2 Natural radionuclide concentration in soil in the study area in comparison with other regions

Regions	Activity concentration (Bq/kg)				Reference
	^{226}Ra	^{238}U	^{232}Th	^{40}K	
Ban Gie, Nghe An	126 (11.9–237)	71 (16.4–143)	155 (22.9–399)	371 (48.4–1250)	This study
Vietnam (63 provinces)	42.8	–	59.8	412	[20]
Ho Chi Minh city, Vietnam	–	23–33	22–25	198–215	[19]
Muong Hum, Vietnam	21.3–6290	23.4–8350	40.9–35,600	123.8–3520	[7]
Bolikhamxay, Laos	44 (13–90)	–	63(11–93)	523(38–999)	[8]
Savannakhet, Laos	22 (7–74)	–	31(4–114)	212(14–906)	[24]
Khammouan, Laos	32.2 (6–68.5)	–	41.6 (8.7–78.9)	279 (32.1–812)	[12]
Southern Thailand	29 (4–122)	–	44 (6–170)	344 (5–1420)	[38]
Perak, Malaysia	112 (12–426)	–	246 (19–1380)	277 (19–2200)	[39]
Johor, Malaysia	162 (12–970)	–	261 (11–1210)	300 (12–2450)	[40]
Penang, Malaysia	396	184	165 (16–667)	835 (87–1830)	[32]
Turkey	21 (10–44)	–	25 (9–37)	299 (144–401)	[37]
Niger Delta, Nigeria	18 (11–40)	–	22 (12–46)	210 (69–530)	[36]
Kerala coast, India	12,300 (max)	–	446 (max)	1390 (max)	[22]
Ullal region, India	25–1290 (282)		1.1–6690 (865)	131–5690(1130)	[23]
South Madagascar	–	1530–4200(2930)	11,000–24,400(14,700)	–	[11]
Guangdong uranium mine, China	174–14,400	225–7540	68–458	675–3280	[41]

natural radionuclides concentration in and close the ore body were shown in Figs. 5 and 6. As presented in these Figs, the Ra_{eq} has been the strongest correlation with ^{232}Th concentration and has been the weakest correlation with ^{40}K concentration. These results were similar to those reported in some previous studies [12, 24].

Table 3 also showed that the absorbed gamma dose (D) varied from 65.9 to 375 nGy/h (294 nGy/h on average) in the ore body and from 30.8 to 270 nGy/h (133 nGy/h on average) close the ore body. The annual effective dose equivalent (AEDE) in the ore body ranged from 80.9 to 460 µSv/y with a mean value of 260 µSv/y while that close the ore body varied from 37.8 to 331 µSv/y with an average of 163 µSv/y. The excess life cancer risk (ELCR) in and close the ore body varied from 0.35×10^{-3} to 1.99×10^{-3} (1.12×10^{-3} on average) and from 0.16×10^{-3} to 1.43×10^{-3} (0.70×10^{-3} on average), respectively. It could be seen that the radiological hazard indices (D, AEDE, ELCR) in the ore body were about 1.6 times higher than those close to the ore body. In the ore body, these indices were about 3.7 times higher than the world average values whereas close to the ore body, those values were about 2.3 times higher than the world average values.

Conclusions

In this study, the concentration of natural radionuclides (^{226}Ra, ^{238}U, ^{232}Th (^{228}Ra), and ^{40}K) in 51 topsoil samples in residential area in and surrounding monazite placer in Ban Gie, Nghe An province, Vietnam were measured and the radiological hazard indices have been estimated. Based on the analysis of the research results, some conclusions have been made as follows:

The research results showed that the area in and close monazite placer has a high radiation background. Accordingly, most of the average studied natural radionuclides concentrations were higher than the world average values, except for ^{40}K. For ^{40}K, the average concentration in the ore body was higher while closing the ore body was lower than the world average value. In comparison between in and close the ore body of study radionuclide activities, the concentrations of ^{226}Ra, ^{232}U in the ore body were insignificant

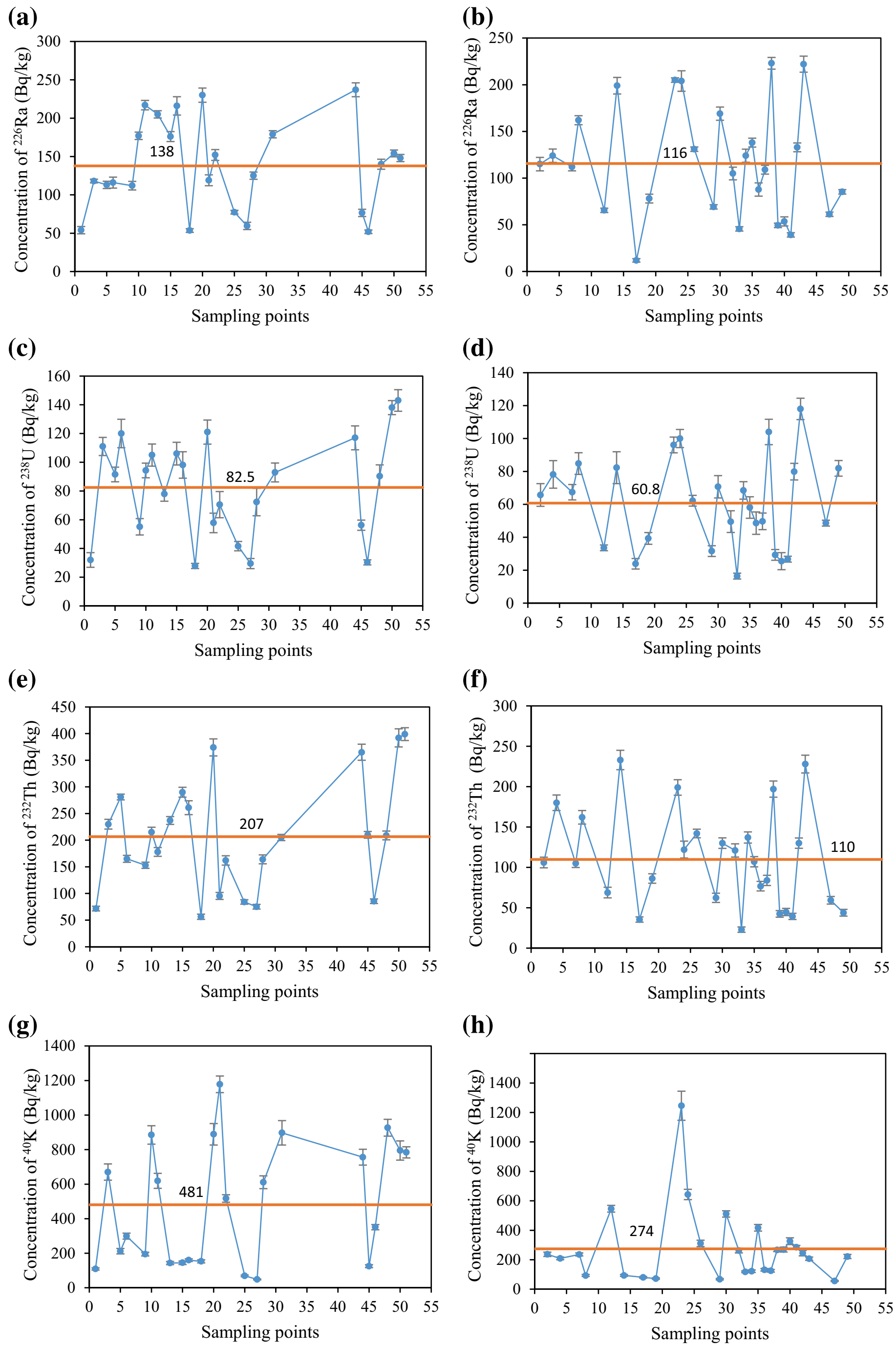

Fig. 4 Variation of ^{226}Ra concentration in the ore body (**a**) and close the ore body (**b**); variation of ^{238}U concentration in the ore body (**c**) and close the ore body (**d**); variation of ^{232}Th in the ore body (**e**) and close the ore body (**f**); and variation of ^{40}K concentration in the ore body (**g**) and close the ore body (**h**)

Table 3 Results of calculated radiological hazard indices

Location	Indices	Average	Maximum	Minimum	SD	World average values[27]
Ore body	Ra_{eq} (Bq/kg)	470	833	146	207	370
	D (nGy/h)	212	375	65.9	92.8	57
	AEDE (μSv/y)	260	460	80.9	114	70
	ELCR($\times 10^{-3}$)	1.12	1.99	0.35	0.49	0.29
Close the ore body	Ra_{eq} (Bq/kg)	294	586	68.7	150	370
	D (nGy/h)	133	270	30.8	67.5	57
	AEDE (μSv/y)	163	331	37.8	82.7	70
	ELCR ($\times 10^{-3}$)	0.70	1.43	0.16	0.36	0.29

differences from those close to the monazite ore body. While the large difference in concentration between in and close the ore body was observed for ^{232}Th and ^{40}K. The concentrations of ^{232}Th and ^{40}K in the ore body were about two times higher than those at close the monazite body. The research results also observed the disequilibrium between ^{238}U and ^{226}Ra concentration and there were positive correlation between of ^{238}U and ^{232}Th and between ^{238}U and ^{226}Ra concentration. By contrast, a weak correlation was found for ^{40}K with other study radionuclides.

Regarding the radiological hazard indices, among studied radionuclides, the concentration of ^{232}Th in and close the ore body showed the strongest correlation with Ra_{eq}. In generally, the radiation hazard indices (D, AEDE, ELCR) in the ore body were about 1.6 times higher than those to close the ore body. These indices in the study area were higher than the world average values from about 2.3 times (close the ore body) to about 3.7 times (ore body).

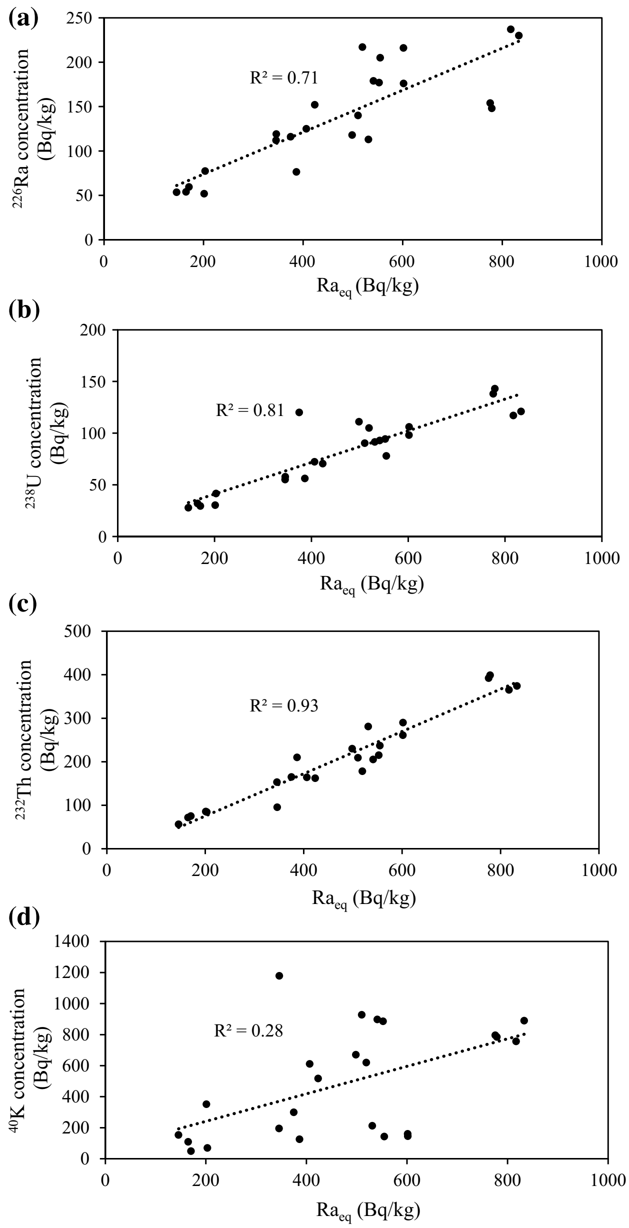

Fig. 5 Correlation between Ra_{eq} and natural radionuclide concentration in the ore body

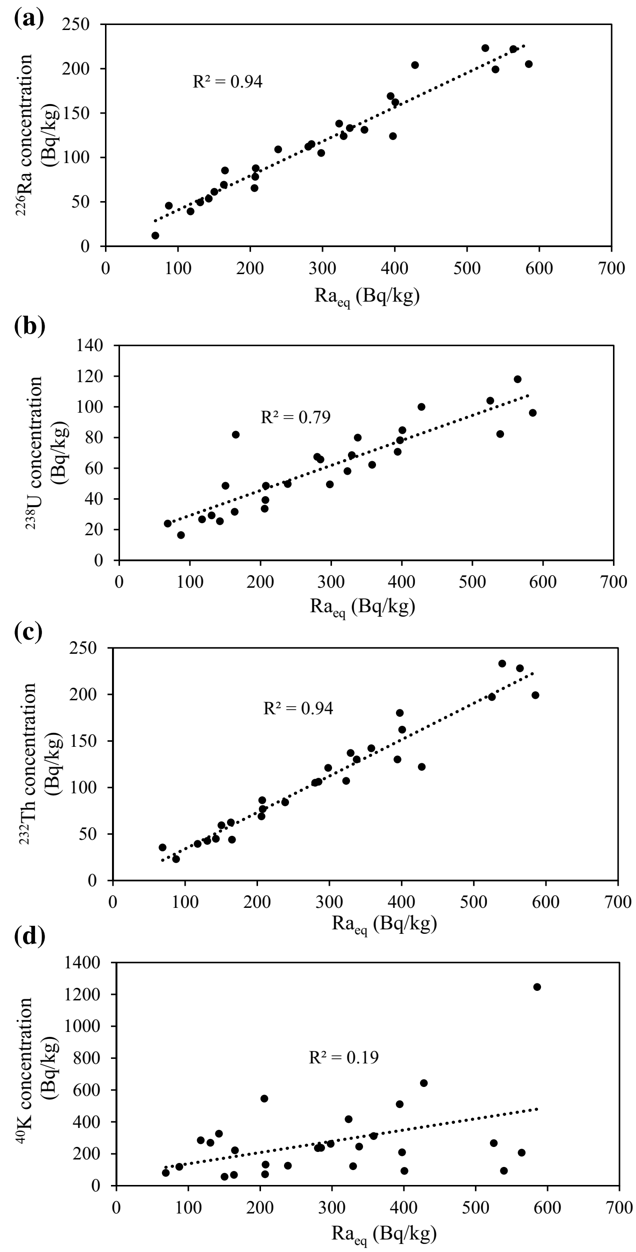

Fig. 6 Correlation between Ra_{eq} and natural radionuclide concentration close the ore body

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