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Original Article

Assessment of Natural Radioactivity and Associated Radiation Hazards in Soils samples from Khammuan Province, Laos

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Abstract: In order to assessment of Natural Radioactivity and Associated Radiation Hazards in soil samples, activity concentration of naturally occurring radionuclides was measured by using a gamma spectrometer with a high energy resolution HPGe detector. The average radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the surface layers (5-30 cm depth) collected from Khammuan province, Laos, were 32.57± 3.35 Bq.kg^{-1},41.10±3.04 Bq.kg^{-1} and 295.07± 17.36 Bq.kg^{-1}respectively. From the activity concentration of ^{226}Ra,^{232}Th and ^{40}K, we derived the parameters using the assessment of the radiological hazard from exposure to these soil samples. The average absorbed dose rate of all measured samples is 52.02±4.09nGy.h^{-1}, while the average annual effective dose in the outdoor due to gamma radioactivity is found to be (0.060±0.005) mSv.y^{-1}.The average values for radium equivalent activity, external and internal hazard indices were found to be (114.07± 4.70) Bq.kg^{-1}, (0.31± 0.02) and (0.39± 0.03) respectively.

Keywords: Natural radionuclides, Radium Equivalent Activity, Absorbed gamma dose rate, Annual effective dose rate, Khammuan province.

1. Introduction

Naturally occurring radionuclides are widespread in the earth's environment during the geological formation, particularly in soil, water, air, rocks and plants. In the world average, approximately 85% of the annual total radiation dose of any person comes from natural radionuclides of both terrestrial

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and cosmogenic origins [1]. The major sources of radiological exposure are natural radionuclides namely ^{238}U and ^{232}Th series and ^{40}K, which appear in the earth's crust since its origin. The external exposure of most of these radionuclides to the human body is cause by their gamma radiation [2, 3]. The ^{226}Ra subseries contribute about 98% of the external γ dose induced by whole ^{238}U series. Radiological hazard parameters are calculated based on the specific radioactivity of ^{40}K, ^{226}Ra and ^{232}Th in the soil samples [4]. Thus, the studies of natural radioactivity in environment is necessary not only for the achieving the impact of radiation, but also for benefit of public health [5]. The main objective of this study was to identify and determine natural radionuclide activity concentrations in soil samples collected from 53 locations in Khammuan Province, Laos to evaluate the annual effective dose from outdoor terrestrial radiation. The natural gamma radiation determined in this study would be useful for establishing baseline data on the gamma background radiation levels indifferent areas of Khammuan Province, Laos for assessment of radiation exposures to the population.

2. Materials and methods

2.1. Study area

Khammuan Province one of the provinces of Laos on latitude 17.6384° N and longitude 105.2195°E as shown in Figure 1, covering an area of 16.315 km^2. The province is bordered by Bolikhamsai Province to the north and northwest, Vietnam to the east, Savannakhet Province to the south and Thailand to the west. Many streams flow through the province to join the Mekong River. Some of the major rivers which originate in the mountains of this province arethe Xaybungfai River (239 km), Nam Hinboun, NamTheun and Namgnum River, situated between the Mekong and the Annamite Range. The Khammuan Plateau features gorges, grottoes, jungles, limestone hills and rivers.

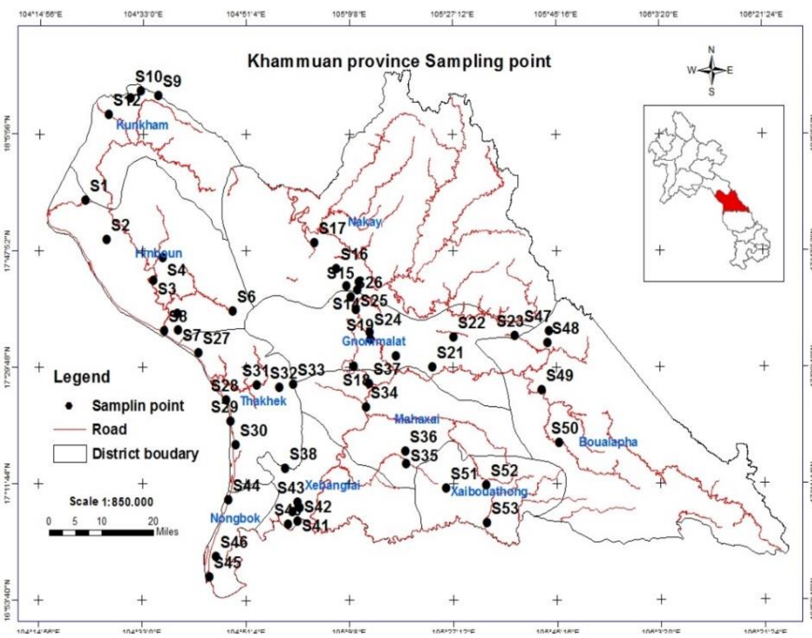

Figure 1. Sampling location in Khammuan Province, Laos.

2.2. Sample preparation and measurements

Soil samples were collected from 53 different locations in Khammuan Province closed to the populated agriculture field and tourist areas. At every sampling site, the soil samples were collected from the surface layers (5-30cm depth) using a spade. After removing organic materials and piece of stones, at the laboratory the samples were dried in an oven at about 110°C for 6 hours. After drying, the samples were crushed and served with a mesh having holes each of diameter of 0.2 mm.

Afterward, the homogenized samples were weighed and placed in polyethylene box with diameter of 7.5 cm and height of 3.0 cm. The time needed for establishing secular equilibrium between ^{226}Ra with ^{214}Bi and ^{214}Pb is about 4 weeks. The gamma spectra of the IAEA –RGU1 reference and the soil samples were carried out by low background gamma spectroscopy using ORTEC P-type coaxial high purity Germanium (HPGe). The detection efficiency of detector is 40% relative to a 3”×3” NaI(Tl) detector and a FWHM of 2 keV at 1332 keV of ^{60}Co.

2.3. Experimental determination of radiation hazards

2.3.1. Determination of activity concentration

The activity concentration of a certain radionuclide was calculated using the following equation [6, 7].

$$A(Bq.kg^{-1}) = \frac{n}{\varepsilon \times I_{eff} \times m_s} \quad (1)$$

where n is the net gamma counting rate (counts per second) for a peak at a given energy, ε is the detected efficiency of a specific gamma-ray, I_{eff} is the intensity of the gamma-ray in radionuclidesand $m_s$is the weight of the soil sample.

The activity of ^{226}Ra was determined based on 295.57 keV and 351.9 keV photo peaks emitted from ^{214}Pb and 609.3 keV and 1120.3 keV peak from ^{214}Bi. The activity of ^{232}Th was extracted by 338.6 keV and 911.1 keV gamma rays of ^{228}Ac and 583.19 keV gamma ray of ^{208}Tl, respectively. The activity of^{40}K was calculated directly from the gamma line of 1460.82 keV.

2.3.2. Radium Equivalent Activity

Radium equivalent activity (Ra_{eq}): The significance of ^{226}Ra,^{232}Th and ^{40}K concentrations was defined in terms of radium equivalent activity in Bq.kg^{-1}. Ra_{eq} was calculated from equation [8]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K, respectively. It has been assumed that 370 Bq.kg^{-1}of ^{226}Ra,259 Bq.kg^{-1} of ^{232}Th and 4810 Bq.kg^{-1} of ^{40}K produce the same gamma dose rate. The maximum value of Ra_{eq} in all soil samples is required to be less than the limit of 370 Bq.kg^{-1} recommended by the Organization for Economic Co-operation and Development for safe use, i.e.to keep the external below 1.5 mSv.y^{-1}[1].

2.3.3. Air absorbed gamma dose rate (D_{air}):

The absorbed dose rates in outdoor air (D_{air}) at 1 m above the ground surface were calculated. The conversion factors used to compute absorbed gamma-ray dose rate in air corresponds to 0.46 nGy.h^{-1} for ^{226}Ra, 0.62 nGyh^{-1} for ^{232}Th and 0.042 nGy.h^{-1} for ^{40}K. Therefore, D_{air} can be calculated using equation [2].

$$D_{air}\ (nGy.h^{-1}) = 0.46\ A_{Ra} + 0.62\ A_{Th} + 0.042\ A_K \quad (3)$$

The population-weighted values give an absorbed dose rate in outdoor air from terrestrial gamma radiation a value of 59 $nGy.h^{-1}$ [1].

2.3.4. Outdoor Annual Effective Dose (OAED)

To estimate outdoor annual effective doses (OAED), we used the conversion dose (0.7 $Sv.Gy^{-1}$) and the outdoor occupancy factor (0.2) [2]. The effective dose equivalent rate was calculated from equation [6]:

$$OAEDE\ (mSv.y^{-1}) = D_{air} \times 8760\ (h.y^{-1}) \times 0.2 \times 0.7\ (Sv.y^{-1}) \times 10^{-6} \quad (4)$$

2.3.5. External and internal Hazard Index

Radiation exposure due to ^{226}Ra, ^{232}Th and ^{40}K may be external. This hazard is defined in terms of external or outdoor radiation hazard index and denoted by H_{ex}, this can be calculated using equation[6]:

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 < 1 \quad (5)$$

Internal hazard index (H_{in}) is given by equation [5]:

$$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 < 1 \quad (6)$$

H_{ex} and H_{in} are must be less than one for safe use of samples and in for the radiation hazard to be negligible.

3. Results and discussion

3.1. Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K

The activity concentrations of radionuclides have been determined by gamma spectrometry technique for 53 soil samples collected from Khammuan Province in Laos. The results of activity concentration for the radionuclides ^{226}Ra, ^{232}Th and ^{40}K are shown the Table 1.

Table 1. Activity concentration ($Bqkg^{-1}$) of ^{226}Ra, ^{232}Th and ^{40}K in soil samples from surface layer (5-30 cm).

S.No.	Activity concentration in $Bq.kg^{-1}$		
	^{226}Ra	^{232}Th	^{40}K
S1	43.67±5.11	60.49±4.01	356.00±38.00
S2	25.31±3.32	42.69±2.70	256.43±24.04
S3	68.51±2.67	46.98±2.17	105.8±19.76
S4	52.98±3.22	63.00±3.92	590.49±35.87
S5	31.59±3.39	33.70±2.48	58.82±11.93
S6	48.76±3.26	56.50±2.71	235.14±22.74
S7	61.51±3.78	53.16±2.96	146.14±26.22
S8	14.85±0.91	22.94±1.40	180.78±11.01
S9	64.83±4.67	35.70±2.57	674.84±43.34
S10	30.27±6.51	52.76±5.20	462.01±25.72
S11	39.99±3.41	76.85±3.32	674.84±19.76
S12	52.77±3.96	50.92±3.98	577.00±30.68
S13	24.07±5.00	43.49±4.16	364.25±19.00
S14	27.65±1.67	43.03±2.59	475.39±28.48
S15	25.81±3.38	33.02±2.78	393.14±12.56
S16	15.99±2.6	31.74±2.10	325.89±8.80
S17	10.45±1.35	23.96±1.02	430.99±5.55
S18	22.20±3.00	29.12±3.60	86.83±9.61

S19	57.65±4.58	76.09±3.57	336.05±16.55
S20	55.26±2.53	38.91±2.10	40.69±9.21
S21	51.35±7.00	48.89±5.29	67.75±23.60
S22	22.20 ± 2.34	39.05 ± 3.78	376.75 ± 18.71
S23	24.10 ± 1.52	36.17 ± 2.35	352.96 ± 21.65
S24	43.37 ± 2.90	64.34 ± 4.63	455.19 ± 21.10
S25	14.13±1.7	17.26±1.49	140.19±6.68
S26	46.02 ± 2.98	72.78 ± 4.68	992.42 ± 62.88
S27	38.87±3.83	62.63±3.06	560.44±14.91
S28	29.95 ± 2.71	30.32 ± 1.96	127.55 ± 8.29
S29	44.49±2.08	36.22±1.89	356.87±21.53
S30	32.44 ± 1.95	29.09 ± 1.67	140.06 ±8.85
S31	9.08±4.62	19.82±3.79	131.07± 13.82
S32	49.03±3.22	34.34±2.42	44.86±10.82
S33	35.70±4.35	58.59±3.41	409.35±16.42
S34	34.99 ± 0.61	66.18 ± 3.60	371.40 ± 6.90
S35	21.19±3.18	25.89±2.23	210.29±10.03
S36	30.77±3.4	67.17±3.00	280.53±12.66
S37	31.15±3.82	36.46±3.11	259.64± 14.09
S38	10.64 ± 2.54	10.72 ±2.72	68.14 ± 6.29
S39	37.21±4.19	20.52±1.09	395.45±16.36
S40	23.81±4.72	29.75±3.74	104.38±16.33
S41	20.72±3.41	12.3±1.05	103.83±12.30
S42	17.96±2.47	24.84±2.08	38.88±8.50
S43	14.76±3.51	19.26±2.81	76.66±12.01
S44	33.13±3.4	48.97±2.70	440.43±13.17
S45	43.42±3.29	70.71±2.72	633.93± 14.11
S46	34.06 ± 2.05	49.97 ± 3.01	381.93 ± 23.08
S47	44.18±3.79	64.14±3.00	723.51±15.34
S48	30.38±2.94	55.92±2.57	343.46±11.24
S49	21.57±3.43	19.84±3.07	116.89±12.22
S50	27.12±3.44	8.74±1.45	49.04±9.22
S51	13.91±2.02	33.91±8.25	489.37±37.01
S52	14.74±3.21	21.56±2.98	80.68±5.53
S53	5.96±1.96	25.09±5.22	32.07±4.52
Average	32.57 ± 3.35	41.10 ± 3.04	295.07 ± 17.36
a*[12]	43.80 ±10.6	57.11 ±14.31	413.90±22.40
b*[9]	42	59	411.93
c*[1]	35	30	400

a* Bolikhamxay Province;b* Vietnam; c* UNSCEAR, 2000

The activity concentration of ^{226}Ra,^{232}Th and ^{40}K in soil samples are compared some other ASEAN countries such as: Vietnam, Thailand, Malaysia and Bolikhamxay Province, Laos. In Vietnam, the activity concentrations of ^{226}Ra,^{232}Th and ^{40}K were 42 Bq.kg^{-1},59 Bq.kg^{-1} and 411.93 Bq.kg^{-1} respectively [4]. In Thailand, the activity concentration of ^{226}Ra,^{232}Th and ^{40}K were 68 Bq.kg^{-1},45 Bq.kg^{-1} and 213 Bq.kg^{-1} respectively [9]. In Malaysia, the activity concentration of ^{226}Ra,^{232}Th and ^{40}K were 66 Bq.kg^{-1},82 Bq.kg^{-1} and 310 Bq.kg^{-1} respectively [10]. In Bolikhamxay Province in Laos [11], the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were 43 Bq.kg^{-1}, 57 Bq.kg^{-1} and 413 Bq.kg^{-1} respectively. It can be clearly seen that ^{226}Ra and ^{232}Th studied values were lower than Vietnam,Thailand, Malaysia and Bolikhamxay Province in Laos. In this work, the values of ^{40}K are higher than Thailand but lower than Vietnam, Malaysia and Bolikhamxay Province,Laos.

The concentration of ^{226}Ra ranges from 5.96 ± 1.96 Bq.kg^{-1} to 68.51 ± 2.67 Bq.kg^{-1}. The lowest ^{226}Ra activity concentration of 5.96 ± 1.96 Bq.kg^{-1} was found in S53 samples. The highest value for ^{226}Ra of 68.51 ± 2.67 Bq.kg^{-1} was found in S3 sample, in Table1. The average radioactivity level for ^{226}Ra (32.57 ± 3.35 Bq.kg^{-1}) is lower than the world average value of 35 Bq.kg^{-1} [1].

The ^{232}Th radioactivity concentration ranges from 8.74 ± 2.45 to 76.86 ± 3.57 Bq.kg^{-1}. The lowest ^{232}Th activity concentration of 8.74 ± 2.45 Bq.kg^{-1} was found in S50 samples. The highest ^{232}Th activity of 76.85 ± 3.57 Bq.kg^{-1} was found in the S11, in Table1. The average radioactivity level of ^{232}Th of 41.10 ± 3.04 Bq.kg^{-1} is higher than the world average of 30 Bq.kg^{-1} [1].

The activity concentration of ^{40}K ranges from 32.07 ± 8.50 Bq.kg^{-1} to 992.46 ± 62.88 Bq.kg^{-1}.The lowest ^{40}K activity concentration of 32.07 ± 8.50 Bq.kg^{-1} was found in S53 samples. The highest ^{40}K activity concentration of 992.46 ± 62.88 Bqkg^{-1} was found in S26 samples, in Table1. The average value of ^{40}K is 295.07 ± 17.36 Bqkg^{-1}. This value is lower than the world average of 400 Bq.kg^{-1} [1].

3.2. Radiological Hazard Assessment

In order to assess the health effects, the absorbed does rate, the outdoor annual effective dose, external hazard index and internal hazard index have been calculated from the activity concentrations of ^{226}Ra,^{232}Th and ^{40}K using equations (3),(4), (5), (6) respectively. The results shown in Table 2 depict that the absorbed dose rates due to the terrestrial gamma ray at 1m above from the ground are in the range of 14.18nGy.h^{-1} to 105.99 nGy.h^{-1} with an average of 52.02 nGy.h^{-1}.This value is lower than the world average value of 59 nGy.h^{-1} [1]. The outdoor annual effective dose rates are in the range of 0.01mSvy^{-1} to 0.13 mSvy^{-1}with an average of 0.06 mSv.y^{-1} in the soil samples, which is lower than the world average value of 0.07 mSv.y^{-1} [1]. On the other hand, the calculated values of the external radiation hazard index range from 0.08mSv.y^{-1} to 0.61mSv.y^{-1} with an average value of 0.31mSv.y^{-1} and the internal radiation hazard index range from 0.11mSv.y^{-1} to 0.73mSv.y^{-1} with an average value of 0.39mSv.y^{-1}, which are far less than unity indicating the non - hazardous category of the samples.

Table 2. Radium equivalent activity(Ra_{eq}), gamma-ray absorbed dose (D), outdoor annual effective dose (OAED),external andinternalhazard index (H_{ex},H_{in})in soil samples from surface layer (5-30 cm) in Khammuan Province, Laos.

S.No.	Ra_{eq}(Bqkg^{-1})	D(nGy.h^{-1})	OAED(mSv.y^{-1})	(H_{ex})	(H_{in})
S1	157.58±13.77	71.31±6.35	0.08±0.007	0.43±0.03	0.54±0.05
S2	106.10±9.01	48.00±4.14	0.05±0.005	0.28±0.02	0.35±0.03
S3	143.84±7.29	64.25±3.36	0.07±0.004	0.39±0.01	0.57±0.03
S4	188.53±11.58	86.90±5.33	0.11±0.006	0.51±0.03	0.65±0.04
S5	88.75±8.78	39.23±4.05	0.04±0.004	0.24±0.02	0.32±0.03
S6	147.66±8.87	66.23±4.07	0.08±0.004	0.39±0.02	0.53±0.03
S7	148.78±10.03	66.41±4.61	0.08±0.005	0.40±0.03	0.56±0.04
S8	61.57±3.77	28.16±1.72	0.03±0.002	0.16±0.01	0.21±0.01
S9	167.84±11.68	79.51±5.51	0.09±0.006	0.45±0.03	0.62±0.04
S10	141.29±15.92	64.91±7.21	0.07±0.008	0.38±0.04	0.46±0.06
S11	201.85±9.67	92.72±4.39	0.11±0.005	0.54±0.03	0.65±0.04
S12	170.01±12.01	78.99±5.49	0.09±0.006	0.45±0.03	0.60±0.04
S13	106.61±12.41	48.23±5.59	0.05±0.006	0.28±0.03	0.35±0.05
S14	125.78±7.26	58.42±3.38	0.07±0.004	0.34±0.02	0.41±0.02
S15	95.60±8.32	43.96±3.75	0.05±0.004	0.26±0.02	0.32±0.05
S16	36.77±6.28	16.59±2.82	0.02±0.003	0.09±0.01	0.14±0.02

S17	40.49±3.23	18.66±1.46	0.02±0.001	0.11±0.08	0.13±0.01
S18	70.53±8.88	31.35±3.94	0.03±0.004	0.19±0.03	0.25±0.03
S19	192.33±10.95	86.30±4.94	0.11±0.006	0.52±0.02	0.67±0.04
S20	114.03±6.24	50.57±2.81	0.06±0.003	0.30±0.01	0.45±0.02
S21	126.47±16.38	55.88±7.39	0.06±0.009	0.34±0.04	0.48±0.06
S22	107.05±9.18	49.39±4.13	0.06±0.005	0.28±0.02	0.34±0.03
S23	103.00±6.54	47.55±3.02	0.05±0.003	0.27±0.01	0.34±0.02
S24	170.43±11.14	77.62±4.99	0.09±0.006	0.47±0.03	0.57±0.04
S25	49.61±4.34	22.73±1.95	0.02±0.002	0.14±0.01	0.17±0.01
S26	225.75±14.51	105.99±6.80	0.12±0.008	0.61±0.03	0.73±0.04
S27	171.58±9.35	78.91±4.22	0.09±0.005	0.46±0.03	0.56±0.04
S28	83.13±6.15	37.35±2.77	0.04±0.003	0.22±0.02	0.30±0.02
S29	123.76±5.21	57.17±2.32	0.07±0.002	0.33±0.01	0.45±0.02
S30	158.22±7.04	71.36±3.14	0.08±0.003	0.42±0.02	0.52±0.02
S31	47.51±10.33	21.55±4.56	0.02±0.005	0.12±0.02	0.15±0.04
S32	101.59±7.48	45.13±3.37	0.05±0.004	0.27±0.02	0.41±0.03
S33	151.00±10.47	68.71±4.73	0.08±0.005	0.40±0.03	0.50±0.04
S34	158.22±7.04	71.36±3.14	0.08±0.003	0.42±0.02	0.52±0.02
S35	74.40±7.14	34.09±3.22	0.04±0.003	0.20±0.01	0.26±0.03
S36	148.42±8.66	66.22±3.89	0.08±0.004	0.40±0.02	0.48±0.03
S37	103.28±8.58	47.09±3.80	0.05±0.004	0.27±0.02	0.36±0.03
S38	33.21±8.43	14.18±3.80	0.02±0.004	0.08±0.02	0.11±0.03
S39	97.00±7.00	45.99±3.27	0.05±0.004	0.26±0.02	0.36±0.03
S40	74.38±11.32	33.20±5.11	0.04±0.006	0.20±0.03	0.26±0.04
S41	46.30±5.85	21.28±2.72	0.02±0.003	0.12±0.02	0.18±0.02
S42	56.47±6.09	24.82±2.74	0.03±0.003	0.15±0.02	0.20±0.02
S43	48.20±8.54	21.57±3.81	0.02±0.004	0.13±0.02	0.17±0.03
S44	137.07±8.27	63.05±3.73	0.07±0.004	0.37±0.02	0.45±0.03
S45	193.34±7.39	88.92±3.26	0.10±0.004	0.52±0.02	0.63±0.03
S46	134.92±8.13	61.64±3.72	0.07±0.004	0.36±0.02	0.45±0.02
S47	191.61±9.26	89.06±4.19	0.10±0.005	0.51±0.03	0.63±0.04
S48	136.79±7.48	61.91±3.36	0.07±0.004	0.36±0.02	0.45±0.03
S49	58.94±8.76	26.74±3.93	0.03±0.004	0.15±0.02	0.22±0.03
S50	43.39±7.64	19.81±3.43	0.02±0.004	0.12±0.02	0.19±0.02
S51	100.06±22.66	47.16±10.19	0.05±0.01	0.27±0.06	0.31±0.08
S52	51.78±8.34	23.11±3.74	0.02±0.004	0.14±0.02	0.18±0.03
S53	44.31±10.08	19.14±4.39	0.02±0.005	0.12±0.02	0.13±0.03
Ar.	114.03±9.03	52.02±4.09	0.06 ±0.005	0.31±0.02	0.39±0.03
a*[1]	370	59	0.07	1	1

a* UNSCEAR,2000

From table 2, we saw that the average values of all five radiological hazard indices in Khammuan Province. The radium equivalent activity (Ra_{eq}), gamma-ray absorbed dose (D), outdoor annual effective dose (OAED), external and internal hazard index (H_{ex},H_{in}) were lower than those recommended values[1].

3.3. Contour maps of radiological hazard indices

Furthermore, the contour maps of three radiological hazard indices which were the radium equivalent activity (Ra_{eq}), external and internal hazard index (H_{ex},H_{in}) from 53 soil samples at depth 5-30 cm collected from Khammuan Province, Laos and shown in Figure 2, 3 and 4.

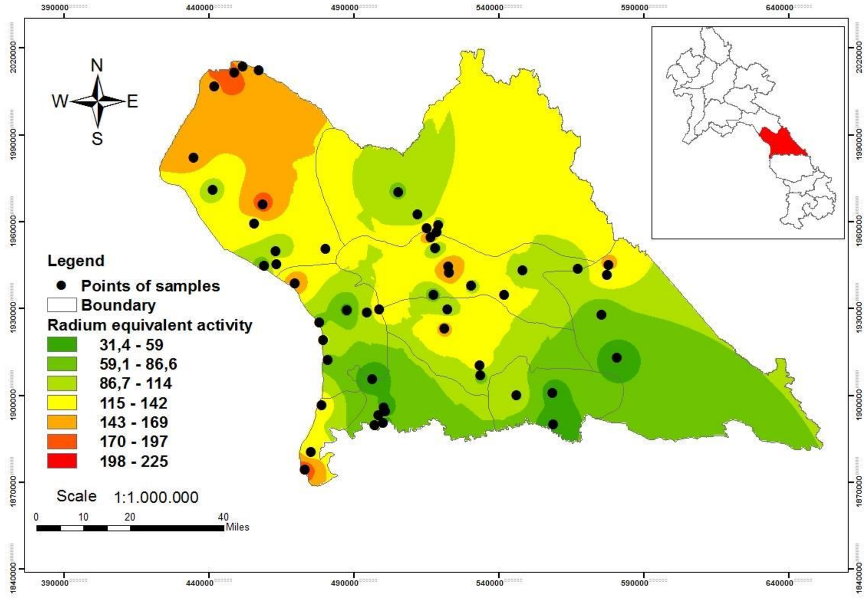

Figure 2. The contour map of the radium equivalent activity (Ra_{eq}) from 53 soil samples at depth 5-30 cm collected from Khammuan Province, Laos.

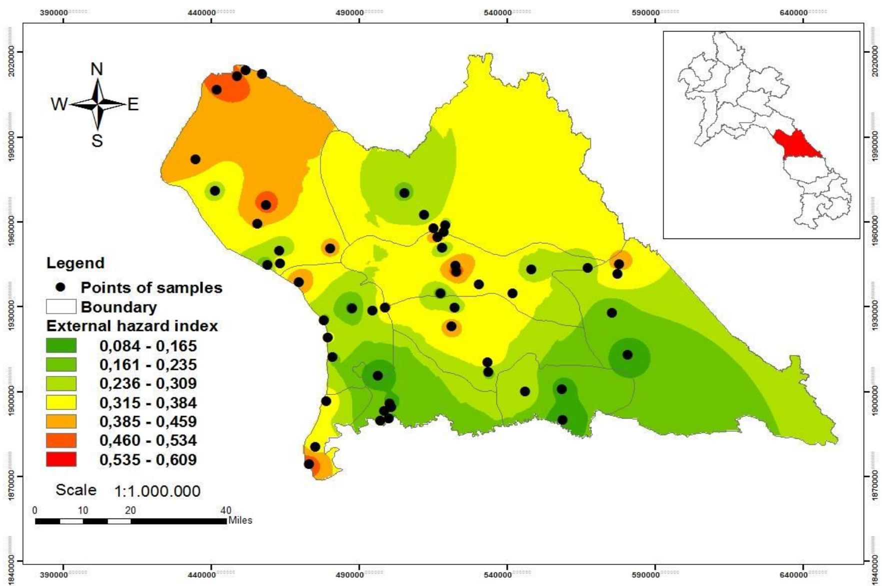

Figure 3. The contour map of the external hazard index from 53 soil samples at depth 5-30 cm collected from Khammuan Province, Laos.

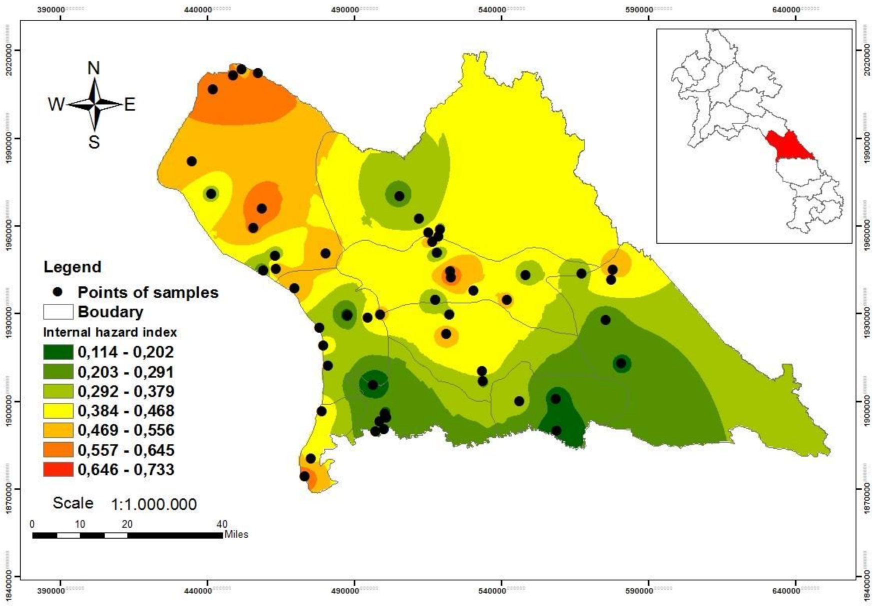

Figure 4. The contour map of the internal hazard index from 53 soil samples at depth 5-30 cm collected from Khammuan Province, Laos.

4. Conclusion

Gamma spectrometry was used to measure the radioactivity concentration of 53 soil samples collected from 10 districts in the Khammuan province in the middle of Laos. The average value of the activity concentration of ^{232}Th with soil samples taken from surface layer (5-30 cm) was 41.10±3.04 Bq.kg^{-1} which is higher than that of the world average values 30 Bq.kg^{-1}. However, activity concentrations of ^{226}Ra and ^{40}K were 32.57± 3.35 Bq.kg^{-1} and 295.07± 17.36 Bq.kg^{-1}, which are lower than that of the world average values 35 Bq.kg^{-1} and 400 Bq.kg^{-1} [1]. For each sample, radium equivalent activity (Ra_{eq}), absorbed dose, outdoor annual effective dose (OAED), the external radiation hazard index (H_{ex}) and internal radiation hazard index(H_{in}) have been confirmed to be the safety for population.

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