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Investigation of Radiological Hazards in the Soil of Mazandaran Province, Iran

Sedigheh Kashian[*1], Mohsen Saleh Kotahi [2], Ali Asghar Fathivand [1], Peyman Lotfalinezhad [2]

1. Radiation Applications Research School, Nuclear Science and Technology Research Institute, Tehran, Iran
2. Physics Department, Toosi University of Technology, Tehran, Iran

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ABSTRACT

Introduction: This paper aimed to outline the procedure for determining the activity concentrations of naturally occurring radionuclides (i.e., ^{226}Ra, ^{232}Th, and ^{40}K) in surface soil samples collected from Mazandaran province, Iran.

Material and Methods: In total, 61 samples were collected between longitude 50˚ 34′ and 54˚ 10′ east and latitude 35˚ 47′ and 36˚ 35′ north from uncultivated locations of Mazandaran province, Iran. The measurements were performed by the gamma spectrometry system using a High Purity Germanium detector.

Results: The mean levels of ^{226}Ra, ^{232}Th, and ^{40}K were found to be 20 Bqkg^{-1} (without considering high-level areas), 33 Bqkg^{-1}, and 421 Bqkg^{-1}, respectively. The results were compared with those of different countries across the world. The radiological hazard to the natural radioactivity was assessed by calculating the absorbed dose rate, the radium equivalent activity, the external and internal hazard indices, and the outdoor and indoor annual effective dose rate. The mean radium equivalent without considering three high-level areas was estimated at 100.8 Bqkg^{-1}.

Conclusion: Results indicated that no radiological risk may threat the residents of the areas under study, except for regions near the hot spring in Sadat Shahr and Lavich, Iran. Without considering high-level areas, the mean radium equivalent activity was 100.8 Bqkg^{-1} that was about 73% lower than the permissible maximum. Moreover, internal and external hazard indices were less than the unit. The mean absorbed dose rate, as well as the outdoor and indoor annual effective dose rates were 48.56 nGyh^{-}1, 238.4 µSv y^{-1}, and 292.6 µSv y^{-1}, respectively.

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Introduction

The major source of radiation exposure is related to natural radionuclides. Natural radionuclides can be divided into two categories, namely terrestrial radionuclides and cosmic rays. According to the International Atomic Energy Agency (IAEA) report, 80% of the radiation to which a person is exposed during one year is from natural radionuclides [1] through inhaling radon gas, external and internal exposure to terrestrial radionuclides, and external exposure to cosmic rays. The natural radioactivity levels are different worldwide due to geographical and geological conditions [2]. The natural radioactivity in soil comes mainly from uranium and thorium series and a radioactive isotope of potassium. It is of utmost importance to have knowledge about the levels of background radiation for impact assessment in the future, radiation protection, and exploration [3-8]. Concentrations of terrestrial radionuclides about certain permissible levels in the soil may become a health hazard leading to increased risk of cancer in the high background level areas [9,10]. The mortality rates of gastrointestinal cancers have been reported high in Mazandaran province, and this province is considered a high-risk area [11]. It was also reported that mortality rates were related to different parameters, such as the impact of the geographical region [12]. This study aimed to describe the methodology to find out the possible relationship between the reported mortality rates and levels of natural radionuclides in the soil of the areas under study. For this reason, the activity concentration of natural radionuclides was determined in 61 surface soil samples collected from Mazandaran province, Iran. The radiological indices were estimated using the measured concentrations, and finally, the association between the potential radiological hazards and the collected samples were investigated in this study.

Materials and Methods

Mazandaran province is located in the northeastern of Iran in an area about 24000 km^2. This region is located between longitude 50˚ 34′ and 54˚ 10′ east and latitude 35˚ 47′ and 36˚ 35′ north.

*Corresponding Author: Tel: +982188221222; Fax: +982188221219; Email: skashian@aeoi.org.ir

Figure 1. Sampling sites in Mazandaran province, Iran

In total, 61 samples of the surface soil (0-5 cm) were taken from the uncultivated locations of Mazandaran province, Iran. For each location, an area of 1×1 m^2 was marked, and 5 samples were collected within 5 km of the beginning and end of the crowded towns and villages. Figure 1 shows the sampling sites. The positions of the sites were determined using the Global Positioning System.

To prepare the samples, foreign materials, such as stone, vegetation, and roots were initially removed from the samples, and then the samples were oven-dried at 100℃ for about 4 h to remove any available moisture.

Dried samples were pulverized and sifted through a 1-mm sieve. Subsequently, 300 g of each sample was sealed in a plastic container for at least 4 weeks to reach a secular equilibrium between ^{226}Ra and ^{232}Th and their respective radioactive progenies.

The samples were measured using a High Purity Germanium detector Model 5574 EGPC manufactured by the Intertechnique Company of France along with multi-channel analysis. with an energy resolution of 2 keV at Full-Width Half of Maximum for 1332 keV gamma-ray of 60 Co and relative efficiency of 20%. The background was subtracted before each measurement. Energy and efficiency calibrations were performed using RGU-1, RGTh-1, and RGK-1 reference material prepared by IAEA. Furthermore, the collection time was determined at 60000 s.

The activity concentrations of the soil samples were determined using *Eq* (1)

$$A_c = C_n/P_\gamma.m.\varepsilon(E_\gamma) \quad (1)$$

where A_c is the activity concentration of the radionuclides in the samples given in Bqkg^{-1}, C_n signifies the net count rate under the corresponding photopeak, m indicates the mass of the dried sample in kg, ε (E_γ) presents the absolute detector efficiency, and P_γ is the emission probability of gamma rays.

The concentrations of ^{226}Ra and ^{232}Th were determined using the ^{214}Bi (609.51 keV) and ^{208}Tl (583.19 keV) gamma-ray lines, respectively. The concentration of ^{40}K was determined directly by gamma line 1461 keV.

The minimum detectable activity of the measurements at a 95% confidence level were determined using *Eq* (2) [13,14]:

$$MDA\ (Bq.kg^{-1}) = 4.65\sqrt{BG}/\varepsilon(E_\gamma).P_\gamma.t.m \quad (2)$$

where BG is the number of counts in the interested photopeak area and t signifies the counting time.

The minimum detectable activities for ^{226}Ra, ^{232}Th, and ^{40}K are given in Table 1.

Table 1. Minimum detectable activity for ^{226}Ra, ^{232}Th, and ^{40}K

Radionuclide	Minimum detectable activity (bq.kg^{-1})
^{232}Th	1.7
^{226}Ra	2.5
^{40}K	19.7

Radium equivalent activity was calculated as follows [15,16]:

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (3)$$

where A_{Ra} , A_{Th}, and A_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the samples in Bqkg^{-1}, respectively. The *Eq* (3) was derived from the assumptions that 370 Bqkg^{-1} of ^{226}Ra, 259 Bqkg^{-1} of ^{232}Th, and 4810 Bqkg^{-1} of ^{40}K produce the same radiation dose rates [17]. The maximum permissible value of the radium equivalent is 370 Bqkg^{-1} [18].

The external hazard index (H_{ex}) and internal hazard index (H_{in}) were estimated using *Eqs* (4) and (5), respectively [15, 19].

$$H_{ex} = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (4)$$

$$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810 \quad (5)$$

Internal and external hazard indices must be less than 1 which corresponds to the limit of the radium equivalent activity of 370 Bqkg^{-1}.

The external gamma dose rate (D) at 1 m above ground was calculated using *Eq* (6) [2]:

$$D(nGy/h) = 0.461A_{Ra} + 0.623A_{Th} + 0.0414A_K \quad (6)$$

Moreover, the annual effective dose equivalent to be received by the public can be calculated as follows.

$$E_{Indoor}\left(\frac{\mu Sv}{y}\right) = D\left(\frac{\mu Gy}{h}\right) \times 24h \times 365.25d \times 0.8 \times 0.7\left(\frac{Sv}{Gy}\right) \quad (7)$$

$$E_{Outdoor}\left(\frac{\mu Sv}{y}\right) = D\left(\frac{\mu Gy}{h}\right) \times 24h \times 365.25d \times 0.2 \times 0.7\left(\frac{Sv}{Gy}\right) \quad (8)$$

where D is the external gamma dose rate and 0.7 is a conversion factor to convert the absorbed dose rate to the effective dose equivalent. Furthermore, 0.8 and 0.2 are indoor and outdoor occupancy, respectively, given by the United Nations Scientific Committee on the Effects of Atomic Radiation (2000).

Results

Table 2 tabulates the results of the activity concentrations in measured soil samples. The ^{226}Ra levels of the sample from regions near the hot spring in Sadat Shahr (S_{14}:380.4 Bq kg^{-1}), Ramsar (S_{16}:127.4 Bq kg^{-1}), and Lavich (S_{23}: 3423.4 Bq kg^{-1}) were higher than those in the other samples. Additionally, the contents of ^{232}Th, ^{226}Ra, and ^{40}K in other samples ranged from 13.5 to 97.8 Bq kg^{-1}, 6.6 to 43.2 Bq kg^{-1}, and 46.2 to 821.0 Bq kg^{-1}, respectively. The lowest concentrations of ^{232}Th, ^{226}Ra, and ^{40}K were determined around Noor, Alasht, and Sadat Shahr, Iran, respectively. The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the region under study were 20 Bqkg^{-1}, 33 Bqkg^{-1}, and 421 Bqkg^{-1}, respectively (without considering high-level areas).

To assess potential radiological hazards to the natural radioactivity, Ra_{eq} , H_{in} , H_{ex}, D, E_{Indoor}, and $E_{Outdoor}$ were obtained from specific activities of ^{232}Th, ^{226}Ra, and ^{40}K in the soil samples of Mazandaran province, Iran. Table 3 presents the obtained results.

The radium equivalent activity ranges from 58.6 Bqkg^{-1} to 243.8 Bqkg^{-1} with a mean of 100.8 Bqkg^{-1} (without considering high-level areas) that was lower than the permissible maximum value of 370 Bqkg^{-1} [18].

Table 2. Activity concentrations of ^{232}Th,^{226}Ra, and ^{40}K in the soil samples

Sample code	Coordinates	Activity Concentration (Bq kg^{-1})		
		^{232}Th	^{226}Ra	^{40}K
S_1	N36˚36.108′ , E51˚36.908′	28.9±4.4	22.4±3.0	363.7±3.4
S_2	N36˚38.533′ , E51˚25.764′	39.5±4.0	27.5±2.8	595.1±3.1
S_3	N36˚41.13′ , E51˚22.516′	34.3±6.3	20.5±4.7	502.7±4.5
S_4	N36˚38.434′ , E51˚27.91′	28.4±4.4	19.0±3.1	437.6±3.3
S_5	N36˚41.286′ , E51˚18.371′	26.5±10.0	33.1±5.7	434.8±6.3
S_6	N36˚42.207′ , E51˚ 14.217′	27.6±9.9	27.1±6.0	270.9±7.4
S_7	N36˚42.934′ , E51˚ 9.149′	37.0±4.1	24.3±2.9	552.1±3.1
S_8	N36˚44.311′ , E51˚ 3.472′	50.3±8.2	25.9±2.9	605.2±5.9
S_9	N36˚46.388′ , E50˚ 57.803′	34.8±9.0	17.6±6.6	516.8±6.0
S_{10}	N36˚51.785′ , E50˚ 47.006′	34.3±4.3	25.9±2.9	451.4±3.3
S_{11}	N36˚53.283′ , E50˚43.323′	29.7±9.5	15.5±6.7	373.9±6.6
S_{12}	N36˚51.905′ , E50˚44.151′	29.6±9.7	17.8±6.6	445.0±6.3
S_{13}	N36˚52.007′ , E50˚43.092′	26.3±4.5	31.8±2.7	345.4±3.4
S_{14}	N36˚52.915′ , E50˚41.419′	18.9±11.9	380.4±2.4	46.2±11.4
S_{15}	N36˚52.407′ , E50˚41.416′	26.0±10.5	21.2±6.5	383.7±6.8
S_{16}	N36˚54.13′ , E50˚39.341′	26.9±9.9	127.4±3.7	342.6±6.8
S_{17}	N36˚57.389′ , E50˚36.59′	43.5±8.3	26.4±6.1	538.4±5.9
S_{18}	N36˚34.427′ , E51˚9.771′	97.8±3.1	40.7±2.5	821.0±2.9
S_{19}	N36˚30.669′ , E51˚13.109′	40.9±8.4	22.5±6.3	582.1±5.7
S_{20}	N36˚34.268′ , E51˚58.514′	13.5±12.9	12.5±6.9	348.0±6.8
S_{21}	N36˚33.709′ , E52˚1.415′	22.3±15.1	29.9±9.0	392.1±8.5
S_{22}	N36˚28.251′ , E52˚5.629′	26.1±4.6	27.9±2.8	359.4±3.4
S_{23}	N36˚22.776′ , E52˚2.285′	39.7±8.6	3423.4±1.0	96.9±9.9
S_{24}	N36˚24.286′ , E52˚20.849′	37.9±8.8	31.0±5.9	449.9±6.3
S_{25}	N36˚31.471′ , E52˚19.638′	42.5±8.3	17.8±6.6	473.3±6.1
S_{26}	N36˚35.073′ , E52˚17.163′	35.3±4.2	23.1±3.0	427.7±3.3
S_{27}	N36˚36.729′ , E52˚12.217′	38.8±8.7	9.7±7.2	473.6±6.2
S_{28}	N36˚40.557′ , E52˚27.712′	30.4±9.6	20.8±6.4	451.3±6.3
S_{29}	N36˚41.384′ , E52˚33.415′	19.9±11.3	13.4±6.9	242.4±7.7
S_{30}	N36˚41.384′ , E52˚36.382′	25.0±10.3	21.3±6.4	233.4±7.8
S_{31}	N36˚42.134′ , E52˚42.491′	34.6±4.1	18.9±3.1	392.1±3.3
S_{32}	N36˚42.338′ , E52˚51.527′	23.1±10.7	8.4±7.3	276.8±7.4
S_{33}	N36˚35.079′ , E52˚54.814′	35.9±8.9	14.4±6.8	426.6±6.4
S_{34}	N36˚28.542′ , E52˚51.435′	26.3±10.0	16.4±6.7	336.6±6.9
S_{35}	N36˚35.079′ , E52˚54.814′	23.0±4.9	19.9±3.3	334.4±3.5
S_{36}	N36˚31.168′ , E52˚35.524′	49.8±7.7	43.2±5.3	419.3±6.4
S_{37}	N36˚30.431′ , E52˚44.785′	26.2±10.0	16.6±6.6	351.9±6.8
S_{38}	N36˚19.496′ , E52˚52.315′	51.0±7.7	19.1±6.5	498.6±6.1
S_{39}	N36˚15.002′ , E52˚54.117′	23.8±4.9	14.1±3.4	363.4±3.5
S_{40}	N36˚11.823′ , E52˚56.345′	25.2±10.1	12.9±6.9	270.8±7.3
S_{41}	N36˚4.773′ , E52˚53.536′	21.2±10.9	16.0±6.7	393.5±6.5
S_{42}	N36˚8.332′ , E53˚2.468′	32.9±9.2	11.7±7.0	512.5±6.0
S_{43}	N36˚4.158′ , E53˚4.432′	31.7±4.5	23.3±3.0	506.7±3.2

Sample code	Coordinates	Activity Concentration (Bq kg^{-1})		
		^{232}Th	^{226}Ra	^{40}K
S_{44}	N36˚4.854′ , E52˚52.356′	22.2±10.8	6.6±7.5	489.3±6.1
S_{45}	N36˚3.668′ , E52˚48.837′	36.6±8.9	25.5±6.1	343.4±6.9
S_{46}	N36˚44.511′ , E53˚51.950′	29.9±9.5	7.0±7.4	505.0±6.0
S_{47}	N36˚43.502′ , E53˚44.816′	43.7±8.2	14.8±6.8	441.8±6.3
S_{48}	N36˚42.555′ , E53˚39.617′	30.2±9.7	27.7±6.1	458.9±6.3
S_{49}	N36˚41.484′ , E53˚28.037′	34.3±9.0	9.5±7.2	445.6±6.3
S_{50}	N36˚40.316′ , E53˚23.24′	16.0±5.6	15.0±3.3	273.4±3.7
S_{51}	N36˚36.349′ , E53˚13.520′	30.6±9.5	15.9±6.7	414.3±6.5
S_{52}	N36˚37.334′ , E53˚15.127′	22.6±10.8	15.7±6.7	516.4±6.0
S_{53}	N36˚34.33′ , E53˚10.3′	38.3±8.8	18.8±6.5	510.6±6.0
S_{54}	N36˚34.157′ , E53˚9.606 ′	20.4±5.2	16.7±3.3	327.7±3.5
S_{55}	N36˚27.889′ , E53˚5.411′	41.0±3.9	24.6±2.9	613.3±3.1
S_{56}	N36˚24.557′ , E53˚8.921′	39.6±8.6	22.7±6.3	546.6±5.8
S_{57}	N36˚24.369′ , E53˚5.913′	41.2±8.5	14.0±6.9	507.5±6.0
S_{58}	N36˚19.41′ , E53˚22.893′	28.6±4.4	15.7±3.2	387.0±3.4
S_{59}	N36˚17.662′ , E53˚20.409′	28.3±4.7	16.3±3.3	402.5±3.4
S_{60}	N36˚15.134′ , E53˚29.528′	33.3±9.2	7.4±7.4	348.8±6.9
S_{61}	N36˚13.057′ , E53˚36.543′	50.7±3.8	26.1±2.9	542.0±3.2
Mean		33	20* 83**	421

* without considering high-level areas
** with considering high-level areas

Table 3. Calculated radiological parameters in Mazandaran Province, Iran

Sample Code	Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}	D (nGyh^{-1})	$E_{Outdoor}$ (µSv y^{-1})	E_{Indoor} (µSv y^{-1})
S_1	91.7	0.25	0.31	43.39	212.99	261.39
S_2	129.8	0.35	0.42	61.92	303.98	373.05
S_3	108.3	0.29	0.35	51.63	253.46	311.05
S_4	93.3	0.25	0.30	44.57	218.79	268.50
S_5	104.5	0.28	0.37	49.77	244.32	299.83
S_6	87.4	0.24	0.31	40.90	200.79	246.42
S_7	119.8	0.32	0.39	57.11	280.35	344.06
S_8	144.4	0.39	0.46	68.33	335.44	411.66
S_9	107.2	0.29	0.34	51.19	251.29	308.39
S_{10}	109.7	0.30	0.37	52.00	255.25	313.25
S_{11}	86.8	0.23	0.28	41.13	201.90	247.77
S_{12}	94.4	0.25	0.30	45.07	221.24	271.52
S_{13}	96.0	0.26	0.35	45.34	222.59	273.18
S_{14}	411.0	1.11	2.14	189.05	928.05	1138.94
S_{15}	88.0	0.24	0.29	41.86	205.47	252.16
S_{16}	192.3	0.52	0.86	89.67	440.20	540.24
S_{17}	130.1	0.35	0.42	61.56	302.20	370.87
S_{18}	243.8	0.66	0.77	113.68	558.06	684.87
S_{19}	125.9	0.34	0.40	59.95	294.30	361.18
S_{20}	58.6	0.16	0.19	28.58	140.30	172.18
S_{21}	92.0	0.25	0.33	43.91	215.55	264.53
S_{22}	92.9	0.25	0.33	44.00	216.00	265.08
S_{23}	3487.7	9.43	18.68	1606.93	7888.37	9680.92
S_{24}	119.8	0.32	0.41	56.53	277.50	340.55
S_{25}	115.1	0.31	0.36	54.28	266.45	327.00
S_{26}	106.5	0.29	0.35	50.35	247.16	303.32
S_{27}	101.7	0.27	0.30	48.25	236.86	290.69
S_{28}	99.1	0.27	0.32	47.21	231.76	284.43
S_{29}	60.6	0.16	0.20	28.61	140.45	172.36
S_{30}	75.1	0.20	0.26	35.06	172.09	211.20
S_{31}	98.5	0.27	0.32	46.50	228.27	280.15
S_{32}	62.8	0.17	0.19	29.72	145.91	179.07
S_{33}	98.5	0.27	0.31	46.67	229.08	281.13
S_{34}	79.9	0.22	0.26	37.88	185.95	228.21
S_{35}	75.6	0.21	0.27	37.35	183.34	225.00
S_{36}	146.7	0.40	0.51	68.30	335.28	411.47
S_{37}	81.5	0.22	0.26	38.54	189.21	232.21
S_{38}	130.4	0.35	0.40	61.22	300.53	368.82
S_{39}	76.1	0.21	0.24	36.37	178.55	219.12
S_{40}	69.8	0.19	0.22	32.86	161.30	197.95
S_{41}	76.7	0.21	0.25	36.87	181.02	222.15
S_{42}	98.2	0.27	0.30	47.11	231.25	283.80

Sample Code	Ra_{eq} (Bq kg^{-1})	H_{ex}	H_{in}	D ($nGyh^{-1}$)	$E_{Outdoor}$ (µSv y^{-1})	E_{Indoor} (µSv y^{-1})
S_{43}	107.6	0.29	0.35	51.47	252.65	310.07
S_{44}	76.0	0.21	0.22	37.13	182.27	223.69
S_{45}	104.3	0.28	0.35	48.77	239.43	293.84
S_{46}	88.6	0.24	0.26	42.76	209.92	257.62
S_{47}	111.3	0.30	0.34	52.34	256.93	315.31
S_{48}	106.3	0.29	0.36	50.58	248.31	304.73
S_{49}	92.9	0.25	0.28	44.20	216.96	266.26
S_{50}	59.0	0.16	0.20	28.20	138.44	169.90
S_{51}	91.6	0.25	0.29	43.55	213.76	262.34
S_{52}	87.8	0.24	0.28	42.70	209.60	257.22
S_{53}	112.9	0.30	0.36	53.67	263.45	323.31
S_{54}	71.1	0.19	0.24	33.97	166.78	204.68
S_{55}	130.4	0.35	0.42	62.27	305.70	375.17
S_{56}	121.4	0.33	0.39	57.76	283.56	348.00
S_{57}	112.0	0.30	0.34	53.13	260.82	320.09
S_{58}	86.3	0.23	0.28	41.08	201.65	247.47
S_{59}	87.7	0.24	0.28	41.81	205.24	251.88
S_{60}	81.8	0.22	0.24	38.60	189.47	232.53
S_{61}	140.4	0.38	0.45	66.06	324.27	397.96

Discussion

Measured and reported activity concentrations of radionuclides are given in Table 4. As can be seen from Table 4, the mean activity concentration of ^{226}Ra in the soil of Mazandaran province (20 $Bqkg^{-1}$) is higher than that in the soil samples collected from Turkey (Osmaniye and Kilis) and Egypt; however, it was lower than the world average [2, 20-24].

The mean level of ^{232}Th in the area under study (33 $Bqkg^{-1}$) is lower than that of the world average (45 $Bqkg^{-1}$), India (64 $Bqkg^{-1}$), Pakistan (62 $Bqkg^{-1}$), China (41 $Bqkg^{-1}$), and Romania (38 $Bqkg^{-1}$) [2, 20-24]. Furthermore, the mean activity concentration of ^{40}K (433 $Bqkg^{-1}$) in the soil of Mazandaran is lower than that in the soil of China (440 $Bqkg^{-1}$), Pakistan (671 $Bqkg^{-1}$), Romania (490 $Bqkg^{-1}$); however, it was comparable to that in Croatia (423 $Bqkg^{-1}$) and higher than the world average (412 $Bqkg^{-1}$) [2, 20-24].

As indicated in Table 4, the estimated external and internal hazard indices were higher than the permissible limit around the hot spring in Sadat Shahr (S_{14}) and Lavich (S_{23}), Iran (1), whereas the corresponding values were less than one in other samples.

The range of external gamma dose rates in the soil samples of the area under study was within 28.20-113.68 $nGyh^{-1}$ (without S_{23}) whit a mean of 48.56 $nGyh^{-1}$. Moreover, the maximum values of $E_{Outdoor}$ and E_{Indoor} (sample S_{18}) were 558.1 and 684.9 µSv y^{-1}, respectively (regardless of S_{14} and S_{23} samples). On the other hand, the soil samples collected from Neka, Iran, obtained the minimum values of $E_{Outdoor}$ (138.4 µSv y^{-1}) and E_{Indoor} (169.9 µSv y^{-1}).

Table 4. Comparison of ^{232}Th, ^{226}Ra, and ^{40}K concentrations in the soil of Mazandaran province, Iran with those in other countries

Country	Activity Concentration (Bq kg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
Azerbaijan	25	33	120	[18]
Belgium	26	27	380	[18]
Bulgaria	45	30	400	[18]
Croatia	43	37	423	[18]
China	32	41	440	[18]
Greece	29	28	383	[18]
Egypt	17	18	320	[18]
India	29	64	400	[18]
Pakistan	49	62	671	[18]
Poland	26	21	410	[18]
Romania	32	38	490	[18]
Syria	20	20	270	[18]
Switzerland	40	25	370	[18]
Turkey (Gaziantep)	25	24	289	[21]
Turkey (Sanliurfa)	21	25	299	[20]
Turkey (Osmaniye)	10	12	243	[23]
Turkey (Kilis)	16	15	206	[22]
World average	32	45	412	[18]
Iran (Mazandaran)	20	33	421	Present study

Conclusion

The mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were 20, 33, and 433 $Bqkg^{-1}$, respectively. It was found that the mean levels of ^{226}Ra and ^{232}Th were lower than the world average values (32 and 45 $Bqkg^{-1}$). Moreover, the mean concentration of ^{40}K is higher than the world average (414 $Bqkg^{-1}$). The results also indicated that the concentrations of ^{226}Ra in some sampling sites, mainly Sadat Shahr (380.4 Bq kg^{-1}), Lavich (3423.4 Bq kg^{-1}), and Ramsar (127.4 Bq kg^{-1}) were much higher than those of the world average. These areas are considered non-living areas. From the estimated hazard index values, it is clear that the calculated hazard parameters were lower than the recommended values worldwide, except for those three sampling sites. Fortunately, there was no evidence indicating the tight relationship between the reported mortality rates and levels of natural radionuclides in the soil of the area under study.

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References

1. IAEA. Regulation for the safe transport of radioactive material. IAEA Division of Public Information, 96-00725 IAEA/PI/A47E; 1996.
2. UNSCEAR. Sources, effects and risk of ionizing radiation. In: United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations Publication; New York: USA; 2000.
3. Ramli A T, Wahab A, Hussein M A, Khalik Wood A. Environmental 238U and 232Th concentration measurements in an area of high level natural background radiation at Palong, Johor, Malaysia. J. Environ. Radioact. 2005;80; 287-304.
4. Saghatchi F, Salouti M, Eslami A, Sharafi A. Natural radioactivity levels of 226Ra and 40K in soil of Zanjan province. Radiat. Protect. Dosim. 2010; 141(1), 86-9.
5. 5. Al-Hamarneh IF, Awadallah M. Soil radioactivity levels and radiation hazard assessment in highlands of northern Jordan, Radiat. Meas. 2009; 44:102-10.
6. Kam E, Bozkurt A. Environmental radioactivity measurements in Kastamounu region of northern Turkey. Appl. Radiat. Isot. 2007; 65: 440-4.
7. Ningappa C, Sannappa J, Karunakara N. Study on radionuclides in granite quarries of Bangalore rural district, Karnataka, India. Radiat. Protect. Dosim. 2008; 131(4): 495-502.
8. Ademola A K, Obed R I. Gamma radioactivity levels and their corresponding external exposure of soil samples from tantalite mining areas in Oke-Ogun, south western Nigeria. Radiationprotection. 2012; 47(2): 243-52.
9. Henshaw DL, Eotough JB, Richarbson JB. Radon as a causative factor in induction of myeloid leukaemia other cancer. Lancet. 1972; 355, 1008-15.
10. Asha Rani, Sudhir Mittal, Rohit Mehra, Ramola R C. Assessment of natural radionuclides in the soil samples from Marwar region of Rajasthan India, Appl. Radiat. Isot. 2015; 101:12-126.
11. Mohammadpour Tahamtan RA, Yazdani J, Zare S, Tirgar Fakheri H, Bagheri S. Geographical mapping of gastrointestinal cancer mortality rates in Mazandaran and Golestan provinces, Iran, J Mazand Univ Med Sci. 2014; 23(110): 125-35 (Persian).
12. Currie A. Limits for qualitative detection and quantitative determination. Anal. Chem. 1986; 40, 586-93.
13. Knoll F. Radiation detection and measurements, Third ed. John Wiley & Sons, Inc., New York; USA. 2000.
14. Baldik R, Aytekin H, Erer M. Radioactivity measurements due to natural radiation in Karabük (Turkey). J. Radioanal. Nucl. Chem. 2011; 289 (2), 297-302.
15. Berekta J, Mahew PJ. Natural radioactivity in Australian building materials, industrial waste and by product. Health Phys. 1985; 48, 87-95.
16. UNSCEAR; Radiation exposure from natural sources of radiation. United Nations Publication, New York; USA. 1993.
17. Straden E. Some aspects on radioactivity of building msterials, Phys. Norv.1976; 8, 167-73.
18. UNSCEAR. Sources and effects of ionizing radiation. In: United Nations Scientific Committee on the Effects of Atomic Radiation. United Nations Publication, New York; USA. 2008.
19. Quindos LS, Fernandez PL, Soto J. Building materials as source of exposure in houses. Indoor Air. 1987; 87. 2, 365.
20. Bozkurt A, Yorulmaz N, Kam E, Karahan G, Osmanlioglu AE. Assessment of environmental radioactivity for Sanliurfa region of Southeastern Turkey. Radiat. Meas. 2007; 42, 1387‑91.
21. Osmanlioglu A E, Kam E, Bozkurt A. Assessment of background radioactivity level for Gaziantep region of Southeastern Turkey. Radiat. Prot. Dosim. 2007; 124, 407‑10.
22. Canbazoğlu C, Turhan Ş, Bakkal S, Uğur F A, Gören E. Analysis of gamma emitting radionuclides (terrestrial and anthropogenic) in soil samples from Kilis province in south Anatolia, Turkey. Ann. Nucl. Energy. 2013; 62, 153-7.
23. Ug˘ur FA, Turhan S, Goren E, Gezer F, Yeg˘ingil Z, Sahan H, et al. Survey of distribution of terrestrial radionuclides in surface soil samples in and around Osmaniye province. Turkey. Radiat. Prot. Dosim. 2013; 154, 483‑9.
24. Jabbar A, Arshed W, Bhatti A S, Ahmad S S, Rehman S U, Dilband M. Measurement of soil radioactivity levels and radiation hazard assessment in mid Rechna interfluvial region, Pakistan. J. Radioanal. Nucl. Chem. 2010; 238:371-78.