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[Research]

Monitoring the concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs of soil in Anarak-Khour district, Central Iran

E. Ehsanpour[1], M. R. Abdi[1]*, M. Mostajaboddavati[2], H. Bagheri[3]

1- Physics Department, Faculty of science, University of Isfahan, Iran
2- Nuclear Engineering Department, Faculty of Advance Sciences and Technologies, University of Isfahan, Iran
3- Geological Science Department, Faculty of Science, University of Isfahan, Iran

**Corresponding author's E-mail: r.abdi@phys.ui.ac.ir*

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ABSTRACT

This study was conducted to determine the radioactivity concentration in soil samples of Anarak-Khour district in Central Iran. Totally, Forty eight soil samples from a depth of 10-15 cm were taken from seven different sites for monitoring. The radioactivity concentration of ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K in soil samples was determined, using a high resolution (HPGe detector, p-type) γ-spectrometry with detectors having 55% and 38.5% relative efficiencies. The results showed that the radioactivity concentration ranged from 9.91 ± 0.11 to 4479.95 ± 0.15 $Bq.kg^{-1}$ for ^{238}U, from 5.95 ± 0.14 to 389.72 ± 0.10 $Bq.kg^{-1}$ for ^{232}Th, ≤MDA to 8.89 ± 0.13 $Bq.kg^{-1}$ for ^{137}Cs and from 123.18 ± 0.27 to 5201.42 ± 0.27 $Bq.kg^{-1}$ for ^{40}K in soil samples. The calculated internal and external hazard indices were more than 1 in some sites which showed a high dose for this area. These results could be used as a database in this area because it might be used as a nuclear waste site in the future.

Key words: Radioactivity concentration, Gamma spectrometry, Soil, Anarak-Khour.

INTRODUCTION

The intersection of Uroomieh - Dokhtar Magmatic Belt (UDMB) and the major Great Kavir - Doruneh Fault (GKDF) are two important structural traits in the Anarak - Khour area in Central Iran (Fig. 1). This region is in the north-western corner of the Central-Eastern Iranian micro plate. This terrene is an approximately 2300 km^2 region of medium relief surrounded by fold and thrust belts within the Alpine-Himalayan orogenic system of Western Asia (Bagheri *et al*., 2006a). In the Anarak - Khour area there are Cu, Ni, Co, As, U, Pb, Zn, Au and Ag deposits which are localized in the same area under similar geological environment along the north-western and western surroundings of Anarak-Khour massif (Badham *et al.,* 1976). The Sediments of Meskani and Talmessi in the Anarak Mining Region is located 7 km apart from the place where being mined for copper and nickel until 1960 (Bagheri *et al.,* 2006b). Recently, exploration activities were continued by the Atomic Energy Organization of Iran due to uranium exploration. The most important active mine in the area is Nakhlak Lead Sediment located in 40 km east of Anarak. Places that have a greater radioactivity concentration were selected as sample sites. Then the soil samples of this area were collected from 33° 15' 38.10" N (with 53° 37' 33.03" E) to 34° 12' 37.60" N (with 55° 18' 43.45" E). The studied area is located within the rectangular area and is divided into seven sites as shown in Fig. 2.

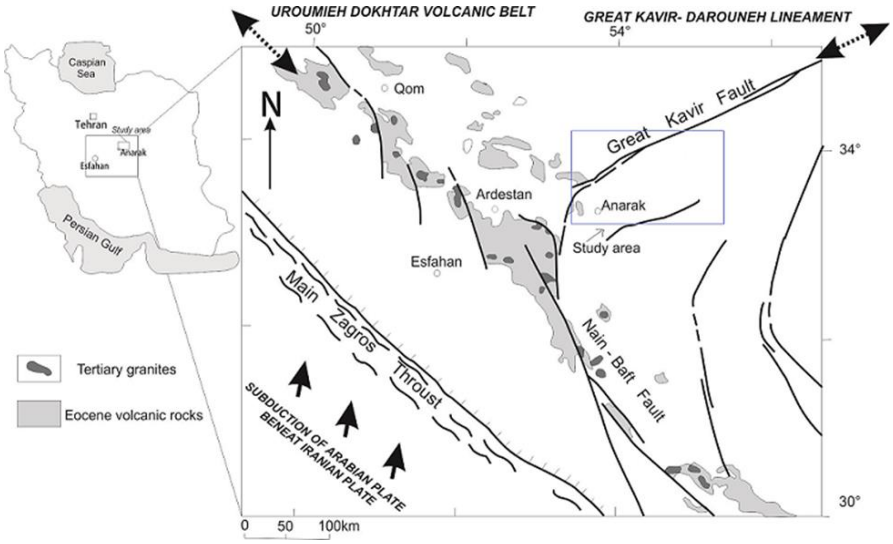

Fig 1. Main structural lineaments in Central Iran and the location of the study area (modified from Bagheri *et al.*, 2007).

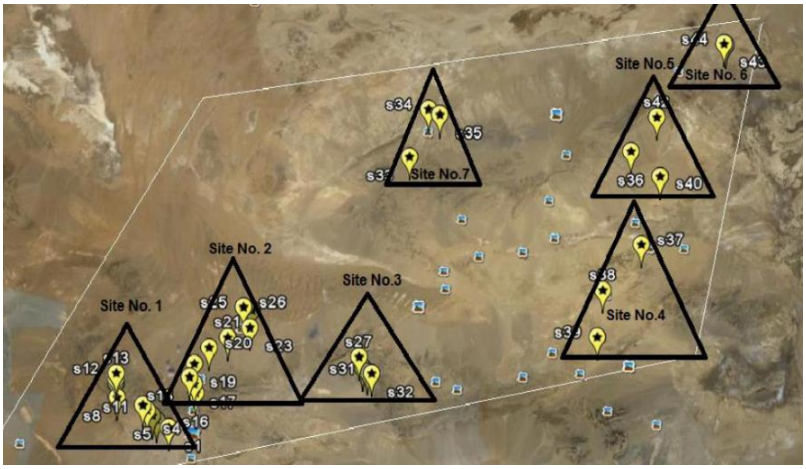

Fig 2. Sampling sites.

There are a lot of researches which deal with determining the radioactivity concentration throughout Iran (2006a, 2006b, 2008; Pourahmad *et al.*, 2008; Abdi *et al.*, 2009, Zare *et al.*, 2012), but there is not enough information about Anarak-Khour area which might be used as a site for nuclear waste. The objective of this study was to determine the radioactivity concentration of ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K in Anarak-Khour area and to estimate possible radiation hazard for the people,in which may possibly affect the investigated area in future.

MATERIALS AND METHODS

Sampling and preparations

Forty eight soil samples from a depth of 10-15 cm were taken from seven different sites. The sample places were chosen in terms of degree-minute-second latitudinal and longitudinal position using a hand-held Global Positioning System (GPS) unit shown in Table 1. Places that are likely to have a greater radioactivity concentration were selected as sample sites so the numbers of samples collected in each site were different. The soil samples were collected from 3 separate holes, with 1 meter width and 10-15 cm depth. The soil samples were dried by spreading them on polythene layers at room temperature for 2 weeks under a controlled environment to avoid local dust pollution. Then, the soil samples were oven dried at 110°C for 24 hours. They were passed through a 50 mesh sieve. 950g of each sample was transferred to Marinelli - beaker. Then, the

Marinelli-beakers were sealed and kept for at least 5 weeks. During this time, the daughter of radon was achieved to equilibrium with ^{226}Ra and the samples were ready to be analyzed by gamma spectroscopy (Abdi *et al.,* 2008, 2009).

Gamma-ray detection system

The activity of ^{238}U (^{226}Ra), ^{232}Th, ^{40}K and ^{137}Cs in the samples were measured using two P-type coaxial HPGe detectors. The relative efficiency of the detectors was 55% with energy resolution of 1.98 keV and 38.5% with energy resolution of 1.8 keV at 1.33 MeV of ^{60}Co. The detectors were kept in a vertical position and shielded by 10 cm thickness lead wall, 2 mm cadmium and 3 mm copper to reduce background radiation (Debertin *et al.,* 1988). Spectrum acquisition was done using the computer software MAESTRO with a multichannel analyzer (4096-channel) and spectrum analysis was done by the OMNIGAM software. In order to measure the activity of a sample, it is necessary to know the detection efficiency of the system by standard sources which have physical dimensions, chemical composition and density similar to the samples. If standard Marinelli beakers are used for standards and samples with similar geometry, the deviation can be reduced almost to zero (Mostajaboddavati *et al.,* 2006).

The reference material IAP-mixed gamma soil standard sources (Institute of Atomic Energy POLATOM, Radioisotope Center) containing ^{241}Am (0.49 ± 0.004 Bq.kg^{-1}), ^{137}Cs (0.09 ± 0.001 Bq.kg^{-1}) and ^{152}Eu (0.11 ± 0.001 Bq.kg^{-1}) were used to obtain efficiency curve. The absolute photopeak efficiencies and activities were determined by using the following equations (Abbas, 2001):

$$y = a_0/x + \sum_{n=1}^{3} a_n (\ln x/x)^n + c \quad (1)$$

$$A = \frac{N}{t \times m \times p \times \varepsilon(E)} \quad (2)$$

Where N, t, m, p and ε (E) are net area counts, time, intensity, sample weight and absolute photo peak efficiency at specific energy, respectively (Faghihian *et al.,* 2012). The specific activity of ^{238}U and ^{226}Ra was determined by gamma-ray lines of ^{214}Bi at 609.3, 1120.3 and 1764.5 keV and ^{214}Pb at 295 and 351 keV, while the specific activity of ^{232}Th was evaluated by gamma-ray lines of ^{228}Ac at 338.4, 911.1 and 968.9 keV. The specific activity of ^{40}K and ^{137}Cs were measured by their 1460.8 and 661.6 keV gamma - ray lines (Abbas, 2001).

The absorbed dose rates (D) are calculated according to UNSCEAR (2000) due to gamma radiation in air, 1m above the ground level for ^{238}U, ^{232}Th and ^{40}K radio nuclides as follows:

$$D\left(^{nGy}/_{h}\right) = 0.462\, A_{Ra} + 0.621\, A_{Th} + 0.0417\, A_K \quad (3)$$

The annual effective outdoor dose rate in units of mSv.year^{-1} is calculated using the hereunder formula (Farai *et al.,* 2005):

$$\text{Effective dose rate}\left(^{mSv}/_{Year}\right) = 1.23 \times 10^{-3} \times \text{Dose rate} \quad (4)$$

The radium equivalent activity is the sum of the studied natural radio nuclides and is based on the hypothesis that 370 Bq.L^{-1} of ^{226}Ra, 259 Bq.L $^{-1}$ of ^{232}Th, and 4810 Bq.L^{-1} of ^{40}K produce the same gamma radiation dose rate (Farai *et al.,* 2005). The maximum value of Ra_{eq} must be less than 370 Bq.L^{-1} for safe use (Abbady, 2004). It is defined as follows:

$$Ra_{eq} = A_{Ra} + 1.43\, A_{Th} + 0.077\, A_K \quad (5)$$

Where A_{Ra}, A_{Th} and A_K are the radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

A hazard index called the external hazard index H_{ex} is defined as follows (UNSCEAR, 2000):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

In addition to the external hazard index, radon and its short-lived progeny are hazardous to the respiratory organs. The internal exposure to radon and its daughter progenies is evaluated by the internal hazard index H_{in}, which is given in the following equation (UNSCEAR, 2000):

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (7)$$

Table 1. Sampling spots information.

No. samples	Longitude	Latitude	altitude
Site No. 1			
1	33°15'38.10"	53°37'33.03"	1286
2	33°16'44.97"	53°35'18.33"	1335
3	33°17'22.80"	53°34'32.30"	1370
4	33°18'10.26"	53°33'34.40"	1413
5	33°18'52.57"	53°32'46.18"	1466
6	33°19'56.50"	53°27'55.61"	1427
7	33°19'53.50"	53°27'57.78"	1421
8	33°19'55.00"	53°28'3.65"	1419
9	33°21'57.36"	53°27'46.70"	1418
10	33°22'5.90"	53°27'47.20"	1424
11	33°22'46.52"	53°27'47.90"	1465
12	33°23'28.00"	53°27'49.30"	1512
13	33°23'28.20"	53°27'51.80"	1523
14	33°23'20.25"	53°27'48.90"	1506
15	33°23'20.25"	53°27'48.90"	1520
Site No. 2			
16	33°20'48.00"	53°42'24.63"	1648
17	33°22'8.52"	53°42'6.18"	1564
18	33°23'8.20"	53°41'14.70"	1450
19	33°25'5.91"	53°42'4.67"	1329
20	33°27'26.80"	53°44'42.92"	1197
21	33°29'0.77"	53°48'3.83"	1137
22	33°29'0.12"	53°48'6.19"	1134
23	33°30'26.60"	53°52'2.69"	1014
24	33°33'1.05"	53°52'23.30"	935
25	33°33'26.80"	53°50'49.72"	1011
26	33°33'27.78"	53°50'49.09"	1006
Site No. 3			
27	33°26'23.43"	54°11'59.17"	1189
28	33°24'47.62"	54°12'40.30"	1146
29	33°24'47.50"	54°12'40.28"	1146
30	33°24'12.33"	54°13'31.96"	1196
31	33°23'58.43"	54°14'18.98"	1263
32	33°23'58.17"	54°14'18.91"	1253
Site No. 4			
33	33°55'38.50"	54°20'49.79"	1210
34	34° 2'39.43"	54°24'15.00"	960
35	34° 1'53.48"	54°26'20.26"	985
Site No. 5			
37	33°43'5.91"	55° 3'22.80"	960
38	33°36'23.62"	54°56'20.96"	906
39	33°29'33.80"	54°55'18.45"	1081
Site No. 6			
36	33°56'41.90"	55° 1'27.22"	948
40	33°53'2.82"	55° 6'50.44"	796
41	33°53'2.82"	55° 6'50.45"	796
42	34° 1'44.81"	55° 6'13.56"	984
Site No. 7			
43	34°12'37.60"	55°18'43.45"	727
44	34°12'35.10"	55°18'42.97"	727
45	34°12'25.05"	55°19'2.25"	729
46	34°12'24.90"	55°19'1.45"	737
47	34°12'21.00"	55°18'58.48"	722
48	34°12'24.90"	55°19'1.45"	737

RESULTS AND DISCUSSION

In this study, duplication of the analysis samples, the blank samples and a standard mixed source containing ^{241}Am, ^{109}Cd, ^{57}Co, ^{133}Ba, ^{137}Cs and ^{60}Co (Institute of Atomic Energy POLATOM, Radioisotope Center) which have a geometry identical to those of the soil samples have been used for quality control procedures. The results of the standard mixed source are shown in Table 2. Also, a routinely daily checking such as energy calibration of the gamma spectroscopy system had been applied. Each sample was analyzed two times and their mean value were calculated and reported here. The recovery in many elements was about 98%.

Table 2. Standard mixed source data.

Radionuclide	Energy (keV) (Intensity %)	Activity (kBq)	Efficiency (%)
Am-241	59.54 keV (35.9%)	3.5 ± 0.03	1.0 ± 0.01
Ba-133	276.39 keV (7.16%)	3.4 ± 0.04	3.3 ± 0.05
	302.85 keV (18.33%)		3.2 ± 0.04
	356.01 keV (62.05%)		2.8 ± 0.03
	383.**84** keV (8.94%)		2.8 ± 0.04
Cs-137	661.66 keV (85.1%)	3.1 ± 0.08	1.7 ± 0.05
Cd-109	88.03 keV (3.61%)	3.8 ± 0.12	2.9 ± 0.1
Co-57	122.06 keV (85.6%)	3.7 ± 0.04	3.5 ± 0.04
	136.47 keV (10.68%)		3.7 ± 0.04
Co-60	1173.24 keV (99.97%)	3.5 ± 0.04	1.1 ± 0.01
	1332.5 keV (99.99%)		1.0 ± 0.01

The radioactivity concentration of ^{238}U (^{226}Ra), ^{232}Th, ^{40}K, and ^{137}Cs in the soil samples collected from different parts of the studied area are given in Table 3. The radioactivity concentration ranged from 9.91 to 4479.95 Bq.kg^{-1} for ^{238}U (^{226}Ra); from 5.95 to 389.72 Bq/kg for ^{232}Th; from 123.18 to 5201.42 Bq.kg^{-1} for ^{40}K and from <MDA to 8.89 Bq.kg^{-1} for ^{137}Cs. A part of Irakan Zone (Site No. 7) has the high radioactivity concentration of ^{238}U and ^{232}Th which might be attributed to the geological structure of the region (Ayoubi *et al.,* 2012). Also, the maximum radioactivity concentration of ^{40}K is found in sample No. 48 (Irakan Zone). The radioactivity concentration of ^{137}Cs in site No. 7 (Irakan Zone) is less than minimum detection analysis (MDA) which may be related to the altitude of this area. Less than MDA radioactivity concentration of ^{137}Cs in site No. 7 is not related to the erosion (Ayoubi *et al.,* 2012; Bagheri *et al.,* 2013). However, because this site has almost the lowest altitude compared to the other sites, accumulation of rainwater in this area caused the ^{137}Cs to deposit in the depth of 10-15 cm where our samples were collected. Fig. 3 shows the distribution of ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K radioactivity concentrations of soil samples in seven sites. To evaluate the studied area, the radioactivity concentration of ^{238}U (^{226}Ra), ^{232}Th, ^{40}K, and ^{137}Cs were compared with those reported from the other parts of Iran and then compared with those that were reported from other countries. By comparing our results with those of other parts in Iran, it is clear that the average radioactivity concentration of ^{238}U (^{226}Ra) and ^{40}K in the studied area is relatively high. The radioactivity concentration of ^{232}Th and ^{137}Cs reported in the North of Iran is higher than those in the studied area. For example, average radioactivity concentration of ^{137}Cs is higher in Guilan (Sadremomtaz *et al.,* 2010). It may be due to the fact that the North of Iran is an agricultural area where fertilizers containing the element are used (Rezaee, 2009). Comparing the results of the present study with the results reported from the other parts of Central Iran (Afshar *et al.,* 2010; Ayoubit *et al.,* 2012 and Rahimi *et al.,* 2013) revealed that radioactivity concentration of ^{137}Cs in this area is less than the other parts. The average radioactivity concentration of ^{238}U (^{226}Ra) of our samples is less than those reported from Malaysia but is higher than the other countries such as China, Egypt, Greece, Kuwait and South Carolina (Travidon *et al.,* 1996; Saad *et al.,*

2002; Yanga *et al*., 2005; Powell *et al.,* 2007; Nasirian *et al.,* 2008; Khan *et al.,* 2011; Kam *et al.,* 2007, 2010 and UNSCEAR, 2000 Morsy *et al*., 2012). The radioactivity concentration of ^{238}U (^{226}Ra) of our samples is higher than acceptable value (35 $Bq.kg^{-1}$). The radioactivity concentration of ^{232}Th of our samples is less than those reported from Malaysia and is approximately equal to acceptable value of 35 $Bq.kg^{-1}$. The radioactivity concentration of ^{40}K in our samples is approximately equal to those reported from the other countries (Table 4). The acceptable value of ^{40}K is 370 $Bq.kg^{-1}$ showing that the value of our data is higher than the acceptable amount. The absorbed dose rates (D), annual effective outdoor dose rate, radium equivalent activity (Ra_{eq}), H_{ex} and H_{in} of our samples are shown in Table 5. The calculated total gamma dose rate varied from 13.41 to 2284.27 $nGy.h^{-1}$ among soil samples due to primordial radio nuclides.

In average, the absorbed dose rate ($nGy.h^{-1}$) in the seven sites is reported in Table 5. The average total gamma dose rate is higher than the worldwide average of 55 $nGy.h^{-1}$ in some sites (Abdi *et al.,* 2009). The annual effective dose obtained in the seven sites ranged from 0.02 mSv in site No. 2 to 2.81 mSv in site No.7 for the background area. If the value of internal or external radiation hazard index is found to be less than unity, then there is no potential internal or external radiation hazard. Both the external (H_{ex}) and internal (H_{in}) radiation hazard indices in some sites are higher than unit indicating that the soils of Anarak - khour area are not free of the radiation hazards.

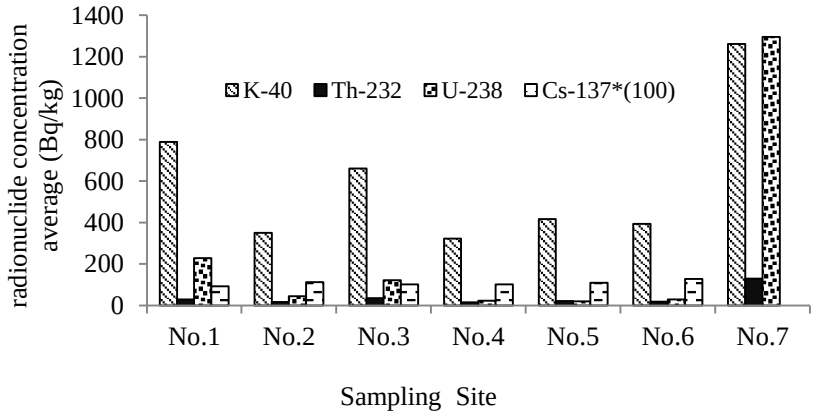

Fig 3. Distribution of radioactivity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in soil samples.

Table 4. Comparison of radioactivity of soils with other areas of the world.

Position	**^{238}U ($Bq.kg^{-1}$)**	**^{232}Th ($Bq.kg^{-1}$)**	**^{137}Cs ($Bq.kg^{-1}$)**	**^{40}K ($Bq.kg^{-1}$)**
Our samples	263.80	37.45	1.88	646.78
Iran	28	22	-	640
China	112	71.5	-	672
Egypt	6.57	8.46	-	1363
Greece	214	43	-	1130
Kuwait	36	6	-	227
Malaysia	860.57	637.61	-	-
Pakistan	-	43.27	-	418.27
South Carolina	37.8	45.3	-	609.3
Turkey	-	30	8.02	431.43
Turkey	-	110.4	19.39	1273
Acceptable value	35	35	-	370

Table 3. Radioactivity concentration of ^{238}U, ^{232}Th, ^{137}Cs and ^{40}K in soil samples.

No. samples	238U(Bq.kg^{-1})	232Th(Bq.kg^{-1})	137Cs(Bq.kg^{-1})	40K(Bq.kg^{-1})
1	22.53 ± 0.12	21.29 ± 0.08	0.77 ± 0.09	420.55 ± 0.18
2	28.84 ± 0.12	27.2 ± 0.09	1.72 ± 0.09	509.89 ± 0.18
3	21.13 ± 0.08	21.25 ± 0.10	1.33 ± 0.10	399.25 ± 0.18
4	20.79 ± 0.12	16.44 ± 0.08	1.04 ± 0.09	312.94 ± 0.18
5	19.03 ± 0.12	13.71 ± 0.09	1.27 ± 0.09	238.95 ± 0.18
6	422.75 ± 0.13	38.71 ± 0.10	0.79 ± 0.09	1118.57 ± 0.18
7	508.42 ± 0.13	48.35 ± 0.09	1.14 ± 0.10	1474.00 ± 0.18
8	699.00 ± 0.13	27.92 ± 0.11	≤MDA	737.64 ± 0.18
9	22.12 ± 0.12	23.53 ± 0.11	≤MDA	527.87 ± 0.27
10	18.91 ± 0.10	23.74 ± 0.12	≤MDA	459.38 ± 0.27
11	37.52 ± 0.12	11.54 ± 0.12	1.45 ± 0.13	192.68 ± 0.27
12	85.73±0.13	44.80 ± 0.13	2.36 ± 0.13	1587.14 ± 0.27
13	247.54 ± 0.13	34.78 ± 0.13	2.13 ± 0.13	1155.14 ± 0.27
14	550.73 ± 0.13	40.66 ± 0.14	≤MDA	1597.19 ± 0.27
15	724.69 ± 0.13	37.88 ± 0.12	≤MDA	1115.60 ± 0.27
16	13.70 ± 0.13	17.83 ± 0.11	3.69 ± 0.13	443.09 ± 0.27
17	20.45 ± 0.12	23.08 ± 0.11	≤MDA	528.13 ± 0.27
18	16.47 ± 0.12	22.13 ± 0.11	1.50 ± 0.13	490.69 ± 0.27
19	9.91 ± 0.11	5.95 ± 0.14	2.03 ± 0.13	123.18 ± 0.27
20	23.49 ± 0.13	27.49 ± 0.11	4.05 ± 0.13	498.64 ± 0.27
21	33.31 ± 0.11	21.19 ± 0.09	6.79 ± 0.09	571.74 ± 0.18
22	229.04 ± 0.12	11.83 ± 0.10	≤MDA	159.82 ± 0.18
23	21.15 ± 0.11	18.90 ± 0.09	1.94 ± 0.09	301.04 ± 0.18
24	22.09 ± 0.12	15.01 ± 0.08	1.60 ± 0.09	311.50 ± 0.18
25	62.27 ± 0.12	15.66 ± 0.11	≤MDA	235.31 ± 0.18
26	34.93 ± 0.12	13.49 ± 0.12	≤MDA	199.36 ± 0.18
27	66.09 ± 0.13	19.67 ± 0.09	4.43 ± 0.09	423.76 ± 0.18
28	28.00 ± 0.13	29.44 ± 0.09	2.40 ± 0.09	821.25 ± 0.18
29	30.81 ± 0.11	31.66 ± 0.08	5.54 ± 0.09	804.61 ± 0.18
30	49.49 ± 0.10	17.55 ± 0.10	0.76 ± 0.11	493.80 ± 0.18
31	42.40 ± 0.11	44.36 ± 0.08	7.07 ± 0.09	1175.25 ± 0.18
32	513.27 ± 0.12	71.27 ± 0.09	≤MDA	246.86 ± 0.18
33	24.21 ± 0.13	13.48 ± 0.09	3.41 ± 0.09	292.43 ± 0.18
34	22.87 ± 0.11	18.81 ± 0.09	5.81 ± 0.09	421.41 ± 0.18
35	21.31 ± 0.11	13.49 ± 0.09	2.30 ± 0.09	253.52 ± 0.18
36	22.26±0.12	10.24 ± 0.09	2.61 ± 0.09	237.10 ± 0.18
37	24.17 ± 0.11	21.25 ± 0.09	4.47 ± 0.09	488.63 ± 0.18
38	18.23 ± 0.11	17.21 ± 0.09	2.82 ± 0.09	329.72 ± 0.18
39	17.59 ± 0.09	26.02 ± 0.09	2.00 ± 0.09	434.46 ± 0.18
40	36.34 ± 0.13	27.42 ± 0.13	≤MDA	429.45 ± 0.27
41	34.90 ± 0.12	11.92 ±0 .13	2.41 ± 0.13	299.76 ± 0.27
42	24.25 ± 0.13	25.69 ± 0.10	8.89 ± 0.13	610.60 ± 0.27
43	228.98 ± 0.14	17.96 ± 0.18	≤MDA	498.48 ± 0.27
44	23.70 ± 0.12	14.93 ± 0.12	≤MDA	487.32 ± 0.27
45	338.25 ± 0.13	16.77 ± 0.13	≤MDA	473.00 ± 0.27
46	4479.95 ± 0.15	315.6 1± 0.17	≤MDA	444.64 ± 0.27
47	31.59 ± 0.12	19.05 ± 0.14	≤MDA	469.10 ± 0.27
48	2667.23 ± 0.18	389.7 2± 0.10	≤MDA	5201.42 ± 0.27
Max	4479.95	389.72	8.89	5201.42
Average	263.8	37.5	1.9	646.8
STD	746.3	67.9	2.2	763.0
CV (%)	282.9	181.3	115.0	118.0

Table 5. Calculated values of absorbed dose rate and annual effective dose, radium equivalent activity, external and internal radiation hazard.

	Absorbed dose rate (nGy.h^{-1})	Annual effective dose (mSv.year^{-1})	Radium equivalent activity (Bq.Kg^{-1})	External radiation hazard index (H_{ex})	Internal radiation hazard index (H_{in})
Sit No. 1					
Min	27.27	0.03	55.36	0.15	0.21
Max	404.85	0.50	856.95	2.34	4.30
Average	156.45	0.19	325.10	0.89	1.51
Site No. 2					
Min	13.41	0.02	27.04	0.08	0.10
Max	119.83	0.15	257.14	0.70	1.32
Average	45.96	0.06	93.87	0.26	0.38
Site No. 3					
Min	54.35	0.07	109.15	0.30	0.44
Max	291.68	0.36	632.47	1.72	3.10
Average	105.92	0.13	218.93	0.61	0.93
Site No. 4					
Min	28.79	0.04	58.35	0.16	0.22
Max	39.82	0.05	79.27	0.22	0.28
Average	33.45	0.04	67.19	0.19	0.25
Site No. 5					
Min	32.86	0.04	65.92	0.19	0.23
Max	44.74	0.06	88.76	0.25	0.31
Average	40.00	0.05	79.96	0.22	0.28
Site No. 6					
Min	26.53	0.03	53.50	0.15	0.21
Max	52.62	0.06	105.61	0.29	0.39
Average	41.73	0.05	83.94	0.24	0.31
Site No. 7					
Min	40.54	0.05	79.16	0.22	0.29
Max	2284.27	2.81	4962.40	13.43	25.53
Average	731.02	0.90	1567.79	4.27	7.76
Min	13.41	0.02	27.04	0.08	0.10
Max	2284.27	2.81	4962.40	13.43	25.53
Average	172.11	0.21	362.64	0.99	1.71

CONCLUSION

The mean radioactivity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in 48 investigated soil samples determined in the present study were within the acceptable limits, but the radioactivity concentration of ^{238}U, ^{232}Th in site No.7 (Irakan Zone) was higher than in the other sites which can be attributed to the geological structure of the region. Preliminary values for the radium equivalent (Ra_{eq}) and radiation hazard index were determined for each of the samples. The average radium equivalent activity was below the defined limit of 370 Bq.kg^{-1}. The external hazard indices were found to be more than 1, indicating a high dose for some areas and also indicating that the areas monitored cannot be regarded as the one having normal levels of natural background Radiation. This study can be followed by analyzing drinking water and plants of the studied area. Moreover, because there are a lot of people who are physically impaired, the birth rate of children with defect should be compared with the radionuclide concentrations in soils, waters and plants every few years. Our results will contribute for data base of this area in future. Then it is necessary that after operating the disposal site of nuclear waste all environment samples of the studied area should be performed every year and compared with our results.

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REFERENCES

Abbady, AGE 2004, Estimation of radiation hazard indices from sedimentary rocks in Upper Egypt. *Applied Radiation and Isotopes*, 60: 111–114.

Abbas, MI 2001, HPGe detector photopeak efficiency calculation including self-absorption and coincidence corrections for Marinelli beaker sources using compact analytical expressions. *Applied Radiation and Isotopes*, 54: 761 - 768.

Abdi, MR, Faghihian, H, Kamali, M, Mostajaboddavati, M & Hassanzadeh, S 2006b, Distribution of natural radionuclides on coasts of Bushehr, Persian Gulf, Iran. *Iranian Journal of Science & Technology*, 30: 259 - 269.

Abdi, MR, Faghihian, H, Mostajaboddavati, M, Hassanzadeh, S & Kamali, M 2006a, Distribution of natural radionuclides and hot points in coasts of Hormozgan, Persian Gulf, Iran. *Journal of Radioanalytical and Nuclear Chemistry*, *270*: 319 – 324.

Abdi, MR, Hassanzadeh, S, Kamali, M & Raji, HR 2009, 238U, 232Th, 40K and 137Cs activity concentrations along the southern coast of the Caspian Sea, Iran. *Marine Pollution Bulletin,* 58: 658 – 662.

Abdi, MR, Kamali, M, Vaezifar, S 2008, Distribution of radioactive pollution of 238U, 232Th, 40K and 137Cs in northwestern coasts of Persian Gulf, Iran. *Marine Pollution Bulletin*, 56: 751 – 757.

Afshar, FA, Ayoubi, Sh, Jalalin, A 2010, Soil redistribution rate and its relationship with soil organic carbon and total nitrogen using 137Cs technique in a cultivated complex hillslope in western Iran. *Journal of Environmental Radioactivity*, 101: 606 - 614.

Ayoubi, Sh, Ahmadi, M, Abdi, MR & Abbaszadeh Afshar, F 2012, Relationships of 137Cs inventory with magnetic measures of calcareous soils of hilly region in Iran. *Journal of Environmental Radioactivity,* 112: 45 - 51.

Badham JPN 1976, Orogenesis and metallogenesis with reference to the silver-nickel, cobalt arsenide ore association. *Geological Society, Canada, Special Paper,* 14, 559 - 571.

Bagheri I, Naghdi R & Jalali AM 2013, Evaluation of factors affecting soil erosion along skid trails (Case study; Shafarood Forest, Northern Iran). *Caspian Journal of Environmental Sciences*, 11 (2): 151 - 160.

Bagheri, H & Moore, F 2006a, Alderton DHM, Cu-Ni-Co-As (U) mineralization in the Anarak area of Central Iran. *Journal of Asian Earth Sciences*, 29: 651 - 665.

Bagheri, H, Moore, F & Shamsipour, R 2006b, Tectonic Reactivation and polyphase mineralization in the Anarak area, Central Iran, *Journal of the Geological Society*, 1: 61 - 72.

Debertin, K & Helmer, RG 1988, *Gamma and X-ray spectrometry with semiconductor detectors*, Elsevier, Amsterdam, pp. 225 - 480.

Faghihian, H, Rahi, D & Mostajaboddavati, M 2012, Study of natural radionuclides in Karun river region. *Journal of Radioanalytical and Nuclear Chemistry,* 292: 711 - 717.

Farai, IP & Ademola, JA 2005, Radium equivalent activity concentrations in concrete building blocks in eight cities in Southwestern Nigeria. *Journal of Environmental Radioactivity*, 79: 119 – 125.

Hassanzadeh, S, Kamali, M & Raji. H R 2009, 238U, 232Th, 40K and 137Cs activity concentrations along the southern coast of the Caspian Sea, Iran. *Marine Pollution Bulletin,* 58: 658 – 662.

Kam, E & Bozkurt, A 2007, Environmental radioactivity measurements in Kastamonu region of northern Turkey. *Applied Radiation and Isotopes,* 65: 440 - 444.

Kam, E, Bozkurt, A & Ilgar, R 2010, a study of background radioactivity level for

Canakkale, Turkey. *Environmental Monitoring and Assessment,* 168: 685 - 690.

Khan, HM, Ismail, M, Khan, K & Akhter, P 2011, Measurement of radionuclides and gamma-ray dose rate in soil and transfer of radionuclides from soil to vegetation, vegetable of some northern area of pakistan using γ-Ray spectrometry. *Water Air and Soil Pollution* 219: 129 - 142.

Morsy, Z, El-Wahab, M A & El-Faramawy, N 2012, Determination of natural radioactive elements in Abo Zaabal, Egypt by means of gamma spectroscopy. *Annals of Nuclear Energy*, 44: 8 - 11.

Mostajaboddavati, M, Hassanzadeh, S, Faghihian, H, Abdi, MR & Kamali, M 2006, Efficiency calibration and measurement of self-absorption correction for environmental gamma spectroscopy of soil samples using Marinelli beaker. *Journal of Radioanalytical and Nuclear Chemistry,* 268: 539 - 544.

Nasirian, M, Bahari, I & Abdullah, P 2008, Assessment of natural radioactivity in water and sediment from Amang (Tin Tailling) processing. *The Malaysian Journal of Analytical Sciences,* 12: 150 - 159.

Pourahmad, J, Motallebi, A, Asgharizadeh, F, Eskandari, G R & Shafaghi, B 2008, Radioactivity Concentrations in Sediments on the Coast of the Iranian Province of Khuzestan in the Northern Persian Gulf. *Environmental Toxicology,* 23: 583 - 590.

Powell, B, Hughes, L, Soreefan, A, Falta, D, Wall, M & DeVol, T 2007, Elevated concentrations of primordial radionuclides in sediments from the Reedy River and surrounding creeks in Simpsonville, South Carolina. *J. Environ. Radioact.* 94: 121 - 128.

Rahimi MR, Ayoubi, Sh & Abdi, MR 2013, Magnetic susceptibility and Cs-137 inventory variability as influenced by land use change and slope positions in a hilly, semiarid region of west-central Iran. *J Applied Geophysics*, 89: 68 - 75.

Rezaee, Kh 2009, ^{232}Th and ^{238}U radioactive contaminations of sediments along the South China Sea of east coast Peninsular Malaysia by INAA, International Nuclear Conference 2009 & Exhibition.

Saad, H.R & Al-Azmi, D 2002, Radioactivity concentrations in sediments and their correlation to the coastal structure in Kuwait. *Applied Radiation and Isotopes*, 56: 991 - 997.

Sadremomtaz A, Moghaddam MV, Khoshbinfar S & Moghaddasi A 2010, a comparative study of field gamma-ray spectrometry by NaI (Tl) and HPGe detectors in the South Caspian Region. *Caspian Journal of Environmental Sciences,* 8: 203 - 210.

Travidon, G, Flouro, H, Angelopoulos, A & Sakelliou, L 1996, Environmental study of the radioactivity of the Spas in the Island of Ikaria, Greece. *Radiation protection dosimetry journal,* 63: 63-67.

UNSCEAR 2000, *Sources and Effects of Ionizing Radiation* (Report to the General Assembly), United Nations, New York.

Yanga, Y X, Wu, XM, Jiang, ZY, Wang, WX, Lu, JG, Lin, J, Wang, LM & Hsia, YF 2005, Radioactivity concentrations in soils of the Xiazhuang granite area, China. *Applied Radiation and Isotopes,* 63: 255 - 259.

Zare, M R, Mostajaboddavati, M, Kamali, M, Abdi, M R & Mortazavi, M S 2012, ^{235}U, ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs activity concentrations in marine sediments along the northern coast of Oman Sea using high-resolution gamma-ray spectrometry. *Marine Pollution Bulletin*, 64: 1956 – 1961.

تعیین پرتوزایی ^{238}U، ^{232}Th، ^{40}K و ^{137}Cs در خاک منطقه انارک – خور در مرکز ایران

ا. احسان‌پور[1]، م. ر. عبدی[1*]، م. مستجاب‌الدعوتی[2]، ه. باقری[3]

۱- گروه فیزیک دانشکده علوم، دانشگاه اصفهان، اصفهان، ایران

۲- گروه مهندسی هسته‌ای، دانشکده علوم پیشرفته و فن‌آوری، دانشگاه اصفهان، اصفهان، ایران

۳- گروه علوم زمین‌شناسی، دانشکده علوم، دانشگاه اصفهان، اصفهان، ایران

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چکیده

در این تحقیق میزان پرتوزایی نمونه‌های خاک منطقه انارک- خور در مرکز ایران تعیین شد. برای این منظور، ۴۸ نمونه خاک از عمق ۱۰-۱۵ سانتی‌متری از ۷ بخش مختلف منطقه برداشته شد. پرتوزایی ^{238}U، ^{232}Th، ^{40}K و ^{137}Cs در نمونه‌های خاک با استفاده از آشکارسازهای گامای با قدرت تفکیک بالا (HPGe، نوع p) با بازدهی نسبی ۵۵٪ و ۳۸,۵٪ تعیین شد. نتایج نشان داد که میزان پرتوزایی از ۰/۱۱ ± ۹/۹۱ تا ۰,۱۵ ± ۴۴۷۹/۹۵ بکرل بر کیلوگرم برای ^{238}U، از ۰/۱۴ ± ۵/۹۵ تا ۰/۱۰ ± ۳۸۹/۷۲ بکرل بر کیلوگرم برای ^{232}Th ، از ۰/۲۷ ± ۱۲۳/۱۸ تا ۰/۲۷ ± ۵۲۰۱/۴۲ بکرل بر کیلوگرم برای ^{40}K و از MDA≤ تا ۰/۱۳ ± ۸/۸۹ بکرل بر کیلوگرم برای ^{137}Cs است. ضرایب خطر تابش داخلی و خارجی در برخی از بخش‌ها فراتر از ۱ بودند که نشانگر بالا بودن دز در این ناحیه است. از آن‌جا که ممکن است در آینده بخش پسمانداری هسته‌ای در این منطقه راه‌اندازی شود، این نتایج می‌تواند به عنوان پایگاه داده مورد استفاده قرار گیرد.

*مولف مسئول