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ANALYSIS OF NATURAL RADIOACTIVITY LEVELS IN SOIL SAMPLES AND DOSE ASSESSMENT FOR DIGOR DISTRICT, KARS, TURKEY

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ABSTRAC

The distribution of natural radioactivity in soils collected from uncultivated areas in Digor districts of Kars was investigated by using NaI(Tl) gamma-ray spectrometry. The concentration of the natural radio nuclides ^{226}Ra ^{232}Th,^{40}K and ^{137}Cs in the 55 soil samples from the studied areas range from 21.6±7.0 to 55.7±8.2 Bqkg^{-1}, 45.0±14.7 to 94.7±15.3 Bqkg^{-1}, 474.5±0.0 to 666.5±9.2 Bqkg^{-1} and BDL (Below Detection Limit) to 13.3±1.5 Bqkg^{-1}, respectively. The determined mean values of activity concentrations of ^{226}Ra ^{232}Th and ^{40}K were used to calculate the radiation hazard indices in soil samples. In the studied area, the radium equivalent activity (Ra_{eq}) varied from 131.3 to 195.1 Bqkg^{-1} with the mean value of 171.5 Bqkg^{-1} and the open air absorbed gamma dose rate (ADR) varied from 61.7 to 88.0 nGyh^{-1} with the mean value of 79.0 nGyh^{-1}. The annual effective air dose rate (AED) due to the presence of radionuclides ranged between 75.7 and 107.9 µSv with the average value of 96.8 µSv. The mean value of risk for cancer formation (LCR) during an average human lifetime was determined to be 0.34x10^{-3}. The results presented in this study, has been compared with the average values of similar studies conducted in different regions of the world. The results of the study may constitute a reference for future assessments.

Key Words: Soil, natural radioactivity concentration, gamma ray spectrometry, dose assessment.

INTRODUCTION

The very long-lived radioactive elements existing since the beginning of the earth form the natural radiation level in the environment we live in. Human beings are exposed to

significant amounts of radiation emitted from natural sources of radiation throughout their lives. The greatest contribution to natural radiation originates from radioactive elements such as ^{238}U, ^{232}Th and their daughter products, ^{226}Ra, ^{222}Rn and ^{235}U and also ^{40}K, which are found naturally in the soils, water, air and also building materials (Mehra et al., 2007, UNSCEAR 2000). The other factor that determines the degree of exposure to natural radiation is high-energy cosmic rays coming into the atmosphere of the world. The contributions of cosmic rays to natural radiation depend primarily on the altitude values of the region inhabited by humans, followed by the latitude values of the region inhabited by humans (UNSCEAR 2000, Daryoush 2003). The main purpose of environmental radiation measurements is to investigate whether the area in which humans live is suitable for healthy living in terms of natural radiation. Therefore, the relationship between radionuclides in the environment and the amount of radiation doses that humans are exposed to from environmental sources must be determined, as well as the biological effect of this radiation on humans. In the literature, there are many studies aiming to determine the levels of natural radiation in the soil and the radiation hazard indices that can arise from the natural radionuclides in this soil. (Durusoy et al., 2017, Turhan et al., 2018, Taşkın et al., 2009, Karataşlı et al., 2016, Abu Samreh et al., 2014, Alzubaudi et al., 2016, Rafique et al., 2014, Chandrasekaran et al., 2014, Oyeyemi et al., 2017). The present work purposed to calculate the activity concentration of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K and the activity level of artificial radionuclide ^{137}Cs in soil samples collected from Digor district, and to interpret the radiological indices and their effects on the population who live in this environment.

Digor, the county of Kars, has Armenia on the eastern border, Kars central district on the western and northern border, and Kağızman district on the southern border. Located between 40 ° 22'32 "North latitude and 43 ° 24'45" East longitude. The areas have an average altitude of 1450 meters above sea level. Its surface area is 1136 km² and the total population is 24863. The Digor River is irrigating the district lands located at the eastern end of the Erzurum-Kars Plateau. The county's economy is based on agriculture and animal husbandry.

MATERIALS AND METHODS

In this study, natural radioactivity concentrations were determined experimentally by examining a total of 55 surface soil samples taken from 11 different stations in Digor district and surrounding area, as seen in Figure 1.

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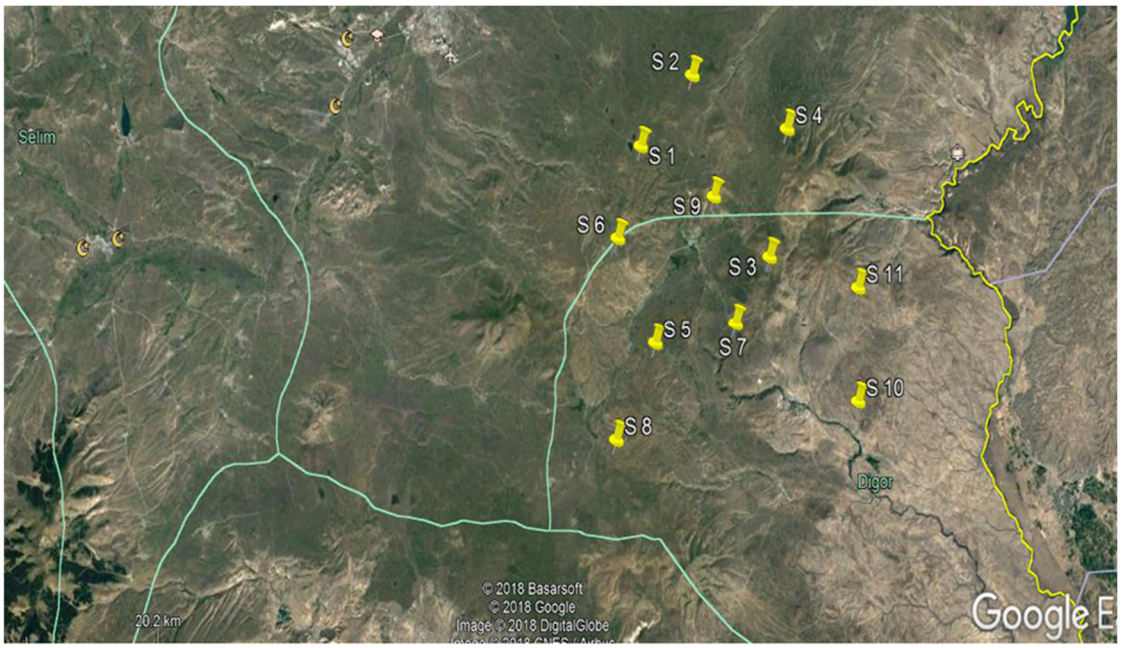

Figure 1 Map of Digor showing the region under investigation.

Surface soil samples were collected from flat areas with a homogeneous distribution defining the region and without agricultural activities close to the settlement areas. The location of each area in which the samples were collected was measured by the GPS (Global Positioning System) device. Samples of approximately 2 kg were taken from 4-6 different sampling points and at different depths ranging from 0-15 cm in each station to provide better sampling in the studied area. The surface soil samples were properly encoded with respect to the location of the sampling site. After removing foreign substances such as plant roots and pieces of stones, the soil samples were powdered and dried in an oven at 105 ^{0}C for 15-20 hours to rout out moisture. The samples sieved with a 2 mm mesh sieve, packed in a plastic containers, weighed and firmly sealed for 30 days to reach secular equilibrium between ^{226}Ra (daughter of ^{238}U) and ^{232}Th with their daughter nuclei. Natural radioactivity concentrations of each sample collected were determined by counting approximately 80000 s using NaI(Tl) scintillation detector based on a gamma-ray spectrometer system. The detector is shielded using 5 cm thick lead layers on all sides to reduce minimize the contribution of building materials and the surrounding radiation.

The output of the detector was analyzed using a MCA (Multi Channel Analyzer) system connected to PC (Personal Computer). Maestro software was used for analyzing the gamma-ray spectra. The energy calibration and the relative efficiency calibration of the gamma spectrometer were performed with standard calibration material (IAEA-375). For determining the activity concentrations, suitable photopeaks at several energies were taken into account and

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the appropriate area (ROI) regions were selected for each peak. ^{226}Ra concentration was found out by measuring the 609.3, 1120.3 and 1764.5 keV gamma-rays from ^{214}Bi. Similarly, 583 keV and 2614.5 keV gamma-rays from ^{208}Tl were used to indicate the activity concentration of ^{232}Th. The activity concentrations of ^{40}K and ^{137}Cs were evaluated from the 1460.8 keV and 661.7 keV gamma lines, respectively. The net count rate under the most significant photo peaks of all radionuclides daughter peaks were determined by subtracting the background spectrum corresponding to the same count time. Afterwards the activity of radionuclide the background subtracted area, is calculated from the significant gamma ray energies (Mehra et al., 2007).

The activities of the radionuclides obtained as a result of the measurements were calculated by using the efficiency of detector and following relation (Tzortzis et al., 2003)

$$Activity(Bqkg^{-1}) = \frac{N_a}{\varepsilon \; x \; t \; x \; M_s \; x \; I_\gamma} \quad (1)$$

where N_a is the net area of a peak at energy, ε is the detector efficiency of the specific gamma-ray line, t is the counting time, M_s is the mass of the sample in kg and I_γ is the intensity of the gamma-ray line in a radionuclide.

Radium Equivalent Activity (Ra_{eq})

The main purpose of measuring radioactivity is to estimate the possible radiation dose to be transmitted to living organisms. Radium equivalent activity (Ra_{eq}) values, measured in Bq $kg^{-1,}$ provide a useful guideline in regulating safety standards on radiation protection for the general public residing in the area under investigation. The Ra_{eq} calculated by equation (2) can be used to assess radiation-related health problems that may occur due to the presence of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in the soil (Beretka and Mathew, 1985).

$$Ra_{eq}(Bqkg^{-1}) = A_{Ra} + (1.43A_{Th}) + (0.077A_K) \quad (2)$$

where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in $Bqkg^{-1}$, respectively. When estimating Ra_{eq} activity according to equation (2), it has been assumed that 1 $Bqkq^{-1}$ of ^{226}Ra, 0.7 $Bqkq^{-1}$ of ^{232}Th and 13 $Bqkq^{-1}$ of ^{40}K produce the same gamma ray dose rates.

Absorbed Dose Rate (ADR)

The effects of gamma radiation from the environmental radioactive sources on human health are generally expressed in terms of the total absorbed gamma radiation dose rate (ADR),

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in the open air at 1 meter above the surface of ground due to natural radionuclides. Equation (3) is used to calculate the total dose ratio (ADR) ($nGyh^{-1}$) by applying conversion factors of 0.462, 0.604 and 0.0417 for measured concentrations of ^{226}Ra, ^{232}Th and ^{40}K in surface soil samples, respectively (EC 1999, Markkanen, 1995).

$$ADR\ (nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_{K} \quad (3)$$

Annual Effective Dose Equivalent (AED)

The annual effective dose equivalent (AED outdoor) exposed by a person to radiation from various radiation sources in outdoor can be estimated by using equation (4) (EC 1999; Turhan et al., 2018, Mehra et al., 2007).

AED (outdoor) (μSv/y) = ADR (nGy h^{-1}) x 0.7 Sv Gy^{-1} x 8760 hours x 0.2 x 10^{-3} (4)

In equation (4), the environmental gamma conversion factor is set at 0.7 $SvGy^{-1}$. This value does not change when measurements are made both indoors and outdoors. In this equation, the outdoor factor is taken as 0.2, which means that people spend 20% of their open time in one year (8760 hours y^{-1}).

Lifetime Cancer Risk (LCR)

Several types of health problems can arise at different times in various parts of the body of people exposed to radiation doses of different sizes given at varying speeds. The increased cancer risk per unit dose can be estimated by comparing the number of cancer patients exposed to a certain amount of radiation with the number of cancer patients with similar characteristics but not exposed to radiation. Increased cancer risk per unit dose is defined as risk factor (RF). The risk of lifetime fetal cancer concerns the possibility of developing a life-long cancer at a certain level of exposure. LCR is calculated by using equation (5) (Oyeyemi et al., 2017).

LCR = AED x LS x RF (5)

Here, the AED is annual effective dose equivalent, LS is mean life span (average 70 years) and RF is a risk factor. For stochastic impacts, ICRP (International Commission on Radiological Protection) exploits RF as 0.05 for the community (UNSCEAR 2000).

RESULTS AND DISCUSSION

The radioactivity concentration values of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs measured in 55 soil samples collected from 11 different sampling stations of Digor district are given in columns 2, 3, 4 and 5 of Table 1. The range of measured activity of ^{226}Ra in the surface soil of Digor district

was 21.6 ± 7.0 Bqkg^{-1} (Uzunkaya Village) to 55.7 ± 8.2 Bqkg^{-1} (Şatıroğlu Village) with an average of 31.3 ± 8.4 Bqkg^{-1}. The range of measured activity of ^{232}Th for the soil samples was 45.0 ± 14.7 Bqkg^{-1} (Borluk Village) to 94.7 ± 15.3 Bqkg^{-1} (Mahirbey Village) with an average of 67.1 ± 13.8 Bqkg^{-1}. The activity concentration of ^{40}K was ranged from 474.5 ± 0.0 Bqkg^{-1} (Mahirbey Village) to 666.5 ± 9.2 Bqkg^{-1} (Yaylacık Village) with an average value of 574.7 ± 7.4 Bqkg^{-1}. The values of the world mean radioactivity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs are 35, 30, 400 and 14.8 Bqkg^{-1}, respectively (UNSCEAR 2000). In this study, the average activity concentration of ^{232}Th and ^{40}K estimated to be about two times higher than the world average value of 35 and 400 Bqkg^{-1}, respectively. Furthermore, the average activity concentration of ^{226}Ra was found to be slightly lower than the world average value of 35 Bqkg^{-1}. The values measured in this study were compared with the values of other reported studies in Turkey and around the world as shown in Table 2. The differences in the activity values of the ^{226}Ra, ^{232}Th and ^{40}K radionuclides might be owing to soil type and the geochemical composition in the region under investigation. The increase of the activity concentration of the naturally occurring ^{40}K radionuclide may depend on animal carcasses and plant residues in soil samples and also grazing of animals in that region.

As can be seen from Table 1, activity concentrations of ^{137}Cs were not measurable in some surface soil samples of the studied stations, since they were lower than the detection limit of 0.75 Bqkg^{-1}. The value of activity concentration the man-made radionuclide ^{137}Cs in all studied soil samples ranges between 1.5 ± 1.3 Bqkg^{-1} (Mahirbey Village) to 13.3 ± 1.5 Bqkg^{-1} (Borluk Village) with an average value of 8.1 ± 1.4 Bqkg^{-1}. The differences in the activities of the ^{137}Cs radionuclide in the soil samples might be transport of radionuclides by rain fall. In addition, the ^{137}Cs radionuclide activity was found to be higher in uncultivated areas where higher altitude.

The radium equivalent activity (Ra_{eq}), absorbed dose rate (ADR), annual effective dose equivalent (AED) and lifetime cancer risk (LCR) were calculated for the soil samples from the investigated area using the obtained values. These calculated results are given in columns 6, 7, 8 and 9 of Table 1.The calculated radium equivalent activity (Ra_{eq}) varied from 131.3 to 195.1 Bqkg^{-1} with an average value of 171.5 Bqkg^{-1}. It is concluded that for all the soil samples examined, the radium equivalent activity value is less than the permissible limits of 370 Bqkg^{-1}.

The absorbed dose rate calculated for the same soil samples vary from 61.7 to 88.0 nGyh^{-1} with an average value of 79.0 nGyh^{-1}. The calculated average of ADR value was found

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to be lower than mean value of Turkey (54.6 nGyh^{-1}) and also mean value of world (60.0 nGy h^{-1}) (TAEK 2010, UNSCEAR 2000).

Using the calculated absorbed dose rate, it was determined that the annual effective dose equivalent (AED) for soil samples varied from 75.7 to 107.9 μSvy^{-1}. The mean value of AED was noticed to be 96.8 μSv y^{-1} which is higher than the average value of world and Turkey (70.0 μSv y^{-1}) (TAEK 2010, UNSCEAR 2000). The calculated lifetime mortal cancer risk values for all the samples range from 0.26x10^{-3} to 0.38x10^{-3} with the mean value of 0.34x10^{-3}. Our result for average value of LCR was found to be very close to be the world's permissible standard of 0.29 x 10^{-3} (UNSCEAR 2000). The Ra_{eq}, ADR, AED and LCR values calculated in Table 2 and some of the published values of radiological hazardous indices are presented.

Table 1 The activity concentrations of natural radionuclides, radium equivalent activity (Ra_{eq}), absorbed dose rate (ADR), annual effective dose (AED) and lifetime cancer risk (LCR) of soils in Digor district.

Sample stations Id and Locations	Activity Concentrations (Bqkg^{-1})				Ra_{eq} (Bqkg^{-1})	ADR (nGyh^{-1})	AED (μSvy^{-1})	ELCR (10^{-3})
	^{238}Ra	^{232}Th	^{40}K	^{137}Cs				
S.1.Borluk	21.9±8.9	45.0±14.7	585.5±2.0	13.3±1.5	131,3	61,7	75,7	0,26
S.2 Çorak Yolu	21.6±10.1	62.4±14.3	557.3±7.8	BDL	153,7	70,9	86,9	0,30
S.3. Dağpınar	29.7±8.9	57.5±13.8	596.4±10.2	7.1±1.4	157,9	73,3	89,9	0,31
S.4. Karakale	22.5±8.5	74.6±13.3	624.0±3.3	BDL	177,2	81,5	99,9	0,35
S.5. Mahirbey	23.2±8.6	94.7±15.3	474.5±1.0	1.5±1.3	195,1	87,7	107,6	0,38
S.6. Şatıroğlu	55.7±8.2	61.9±13.0	579.0±11.8	10.6±1.3	188,8	87,3	107,0	0,37
S.7. Şirin Köy	41.5±8.6	70.4±12.8	630.0±3.2	BDL	190,7	88,0	107,9	0,38
S.8. Yaylacık	45.8±8.4	56.3±13.2	666.5±9.2	BDL	177,6	83,0	101,7	0,36
S.9. Gülheyran	28.8±7.5	62.3±12.9	558.0±11.7	BDL	160,9	74,2	91,0	0,32
S.10.Uzunkaya	21.6±7.0	74.5±13.4	575.2±13.4	BDL	172,5	79,0	96,9	0,34
S.11. Saklıca	31.8±7.5	78.6±14.9	475.2±11.3	BDL	180,8	82,0	100,5	0,35
Mean	31.3±8.4	67.1±13.8	574.7±7.4	8.1±1.4	171,5	79,0	96,8	0,34

BDL; Below dedection limit

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Table 2 Comparison of natural radioactivity levels in soil samples, absorbed dose rate, annual effective dose rate and lifetime cancer risks at present study stations with values reported in literature.

		Activity Concentrations ($Bqkg^{-1}$)				Terrestrial			
References	**Region**	^{226}**Ra**	^{232}**Th**	^{40}**K**	^{137}**Cs**	**Ra_{eq} ($Bqkg^{-1}$)**	**ADR ($nGyh^{-1}$)**	**AED (μSvy^{-1})**	**LCR $X10^{-3}$**
This Study	**Digor**	**31.3±8.4**	**67.1±13.8**	**574.7±7.4**	**8.1±1.4**	**171.5**	**79.0**	**96.8**	**0.34**
Cengiz et al	Sarıkamış	17.9±7.7	30.7±6.8	448.7±34.6	5.8±1.0	95.5	46.9	57.5	0.20
Cengiz et al	Kars Center	47.8	51.08	771.57	18.0		44.76	54.9	
Durusoy et al	Rize	25.5	51.8	344.9	26.3	125	56.9	69.8	
Turhan et al.	Iğdır	19.1±0.6	21.09±0.6	437.7±10.3	11.8±1.1		42	51	0.18
Taşkin et al.	Kırklareli	28±13	40±18	667±282	8.0±5.0		71.0	87.0	0.51
Karatashı et al	Mersin	27.1	34.3	370.5	18.6		51.0	62.0	0.22
Kapdan et al.	Yalova	22.36	26.87	419.32	2.53		48.89	59.96	0.42
Abu Samreh et al	Palestine	41.4	19.5	113.3	2.8	77.6	35.3	40.0	1.02
Rafique et al	Pakistan	31.25 ±0.5	44.1±1.07	575±8.9	15.04±0.3		89	164.0	0.543
Chandrasekaran et al	India	19.16	48.56	1146.88					0.70
Oyeyemi et al	Nigeria	25.498	77.772	710.704			148.22		0.635
Alzubaidi et al	Malaysia	102.08±3.9,	133.96±2.92,	325.8 ±9.8		458.8	141.62	169.0	
TAEA, 2010	Turkey	34.7±1.7	35.4±0.8	450.0±18	11.6±0.5		54.6	70.0	
UNSCEAR 2000	Worldwide	35.0	30.0	400.0		370	60.0	70.0	0.29

CONCLUSION

Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs radioisotopes and also the associated radiation hazard levels in 55 of soil samples from research areas in the 11 different locations of Digor district in Kars were determined by gamma ray spectrometer. The average concentrations of naturally occurring radioisotopes and ^{137} Cs in soil samples are 31.3 ± 8.4, 67.1 ± 13.8, 574.7± 7.4 and 8.1 ± 1.4 $Bqkg^{-1}$, respectively. The mean concentrations of ^{232}Th and ^{40}K are higher than the world average values reported in UNSCEAR (2000). However, the concentrations of ^{226}Ra and ^{137}Cs are very much close to world average values. Radiological hazard indices such as the radium equivalent activity, outdoor absorbed dose rate, annual effective dose equivalent and lifetime cancer risk for adult person living in the region were calculated and found to be 171.5 $Bqkg^{-1}$, 79.0 $nGyh^{-1}$, 96.8 $\mu Sv\ y^{-1}$ and $0.34x10^{-3}$, respectively. These results compared well with average national and world recommended values. According

to results from this study, the region under investigation has normal levels of natural background radiation, therefore, did not pose health risks to the population of the area.

REFERENCES

Abu Samreh, M. M., K. M. Thabayneh, F. W. Khrais 2014. Measurement of activity concentration levels of radionuclides in soil samples collected from Bethlehem Province, West Bank, Palestine, Turkish J Eng Env Sci, 38: 113-125.

Alzubaidi, G., Fauziah B. S. Hamid and I. Abdul Rahman 2016. Assessment of Natural Radioactivity Levels and Radiation Hazards in Agricultural and Virgin Soil in the State of Kedah, North of Malaysia The Scientific World Journal, 1-9.

Beretka, J. and P.J Mathew 1985. Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys., 48, 87–95.

Bilgici Cengiz, G, A. Çağlar 2017. Evaluation of Natural Radioactivity Levels and Radiological Hazards in Soil Samples of Sarıkamış Province, Kars, Turkey. Radiation Science and Technology, 3(6), 68-73.

Cengiz, G. B., S. Reşitoğlu 2014. Determination of natural radioactivity levels in Kars City center, Turkey. Journal of Nuclear Sciences, 1, 32-37.

Chandrasekaran A., R. Ravisankar, G. Senthilkumar, K. Thillaivelavan, B. Dhinakaran, P. Vijayagopal, S.N. Bramha, B. Venkatraman 2014. Spatial distribution and lifetime cancer risk due to gamma radioactivity in Yelagiri Hills, Tamilnadu, India Egyptian journal of basic and applied sciences 1 38-48.

Daryoush Shahbazi-Gahrouei. 2003 Natural Background Radiation Dosimetry in the Highest Altitude Region of Iran, Journal of Radiation Research, 44, 285-287.

Durusoy A., M. Yildirim 2017 Determination of radioactivity concentrations in soil samples and dose assessment for Rize Province, Turkey, Journal of Radiation Research and Applied Sciences, 10, 348-352.

EC, 1999. European Commission. Radiation Protection Unit, radiological protection principles concerning the natural radioactivity of building materials. Radiat. Prot., 112.

Kapdan, E., Varinlioglu, A. and Karahan, G 2011. Radioactivity Levels and Health Risks due to Radionuclides in the Soil of Yalova, Northwestern Turkey Int. J. Environ. Res., 5(4):837-846.

Karataslı M., S. Turhan, A. Varinlioglu, Z. Yegingil 2016. Natural and fallout radioactivity levels and radiation hazard evaluation in soil samples. Environ Earth Sci, 75:424.

Markkanen, M., 1995. Radiation Dose Assessments for Materials with Elevated Natural Radioactivity. Report STUK-B-STO 32. Radiation and Nuclear Safety Authority -STUK.

Oyeyemi K D, M R Usikalu, A P Aizebeokhai, J A Achuka and O Jonathan 2017. Measurements of radioactivity levels in part of Ota Southwestern Nigeria: Implications for radiological hazards indices and excess lifetime cancer-risks IOP Conf. Series: Journal of Physics: Conf. Series 852, 1-8.

Rafique M, S Ur Rahman, M Basharat, W Aziz, I Ahmad, K A Lone, K Ahmad, Matiullah 2014. Evaluation of excess life time cancer risk from gamma dose rates in Jhelum valley. Journal of Radiation Research and Applied Sciences, 7 29-35.

Mehra R., Singh S., Singh K., Sonkawade R 2007. ^{226}Ra, ^{232}Th and ^{40}K analysis in soil samples from some areas of Malwa region, Punjab, India using gamma ray spectrometry. Environ Monit Assess 134, 333-342

TAEK 2010, Türkiye'deki Çevresel Radyoaktivitenin İzlenmesi 2009, Technique Report, Ankara 9-14.

Taskin H., M. Karavus, P. Ay, A. Topuzoglu, S. Hidiroglu, G. Karahan 2009. Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivity in Kirklareli, Turkey. Journal of Environmental Radioactivity, 100, 49-53.

Turhan Ş., E. Gören, F. A. Uğur, M. Karataşlı, Z. Yeğingil 2018. Study of the radioactivity in environmental soil samples from Eastern Anatolia Region of Turkey, Radiochim. Acta, 106(2), 161-168.

Tzortzis, M., H. Tsertos, S. Christofides, G. Christodoulides 2003. Gamma-ray measurements of naturally occurring radioactive samples from Cyprus characteristic geological rocks, Radiation Measurements 37, 221-229.

UNSCEAR 2000. Sources, Effects and Risks of Ionizing Radiation Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly. United Nations, New York.