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Radioactivity Levels and Health Risks due to Radionuclides in the Soil of Yalova, Northwestern Turkey

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ABSTRACT: Naturally occurring radionuclide of terrestrial origin (also called primordial radionuclide) are present in various degrees in all media in the environment, including the human body itself. Their concentrations in environment decrease continually by decaying. The main objective of this study is to evaluate the radioactivity levels and health risks due to terrestrial radionuclide in soil of Yalova, northwestern Turkey. For this purpose, activity concentrations of radionuclide in soil and the environmental outdoor gamma dose rates (terrestrial and cosmic) have been investigated in the city of Yalova. In addition, maps for the radionuclide activity concentrations of soil and the outdoor gamma dose rates distributions have been plotted for the region. The average activities of radionuclide, ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K, and ^{137}Cs in the soil were determined as 17.95 (8.5-37.3) Bq/kg, 26.87 (3.8-43.9) Bq/kg, 22.36 (8.3-41) Bq/kg, 419.32 (197.1-950.0) Bq/kg, 2.53 (0.5-13.4) Bq/kg, respectively, in the region. The average outdoor gamma dose rates due to terrestrial and cosmic radiations were found to be 49 nGy/h and 35 nGy/h with the total of 84 nGy/h outdoor gamma exposure rate in the region. Annual effective dose due to environmental outdoor gamma radiation exposures was determined as 103 nSv with the excess lifetime cancer risk of 0.042 x 10^{-2} in the region. The results of the study were discussed with the studies done in the close cities and the worldwide averages.

Key words: Uranium, Thorium, Potassium, Terrestrial Radiation, Cancer Risk

INTRODUCTION

The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. The knowledge of radionuclide distribution and radiation levels in the environment is important for assessing the effects of radiation exposure to human beings (Mahur *et al;* 2008). There are two main contributors to natural radiation exposures: high-energy cosmic ray particles incident on the earth's atmosphere and radioactive nuclides that originated in the earth's crust and are present everywhere (UNSCEAR, 2000).

The earth is continually bombarded by high-energy particles that originate in outer space. These cosmic rays interact with the nuclei of atmospheric constituents, producing a cascade of interactions and secondary reaction products that contribute to cosmic ray exposures that decrease in intensity with depth in the atmosphere, from aircraft altitudes to ground level (UNSCEAR, 2000).

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Irradiation of the human body from external sources is mainly by gamma radiation from radionuclide in the ^{238}U and ^{232}Th series and from ^{40}K (UNSCEAR, 2000). Rocks are radioactive due to naturally occurring radioactive material (NORM) in the earth's crust. The radioactivity of rocks ultimately shifts to soil. The levels to terrestrial background radiation are related to the type of rock from which the soils originate (Akhtar *et al.*, 2011). External exposures outdoors arise from terrestrial radionuclide present at trace levels in all soils. In terms of natural radioactivity, the igneous rocks of granitic composition are enriched in thorium and uranium, compared to rocks of basaltic. Therefore, higher and lower levels of natural radiation in any area in the world can be associated with igneous and sedimentary rocks, but there are some expectations such that certain shale or phosphate rock and it is to be fault and/or volcanic region (Inceoz *et al.*, 2006; Baykara *et al.*, 2005a). As a result of nuclear explosions carried out in the earth's atmosphere and the Chernobyl nuclear power station accident, the world has become polluted with radionuclide of artificial origin. Some of these long-lived isotopes ^{134}Cs (T1/2 ¼ 2 y) and ^{137}Cs (T1/2¼ 30 y) are still eminent in the environment predominantly in surface soil, as a result of radioactive fall-out from the atmosphere (Celik *et al.,* 2008).

Exposure of cells and organisms to ionizing radiation due to background radiation may cause DNA damage. The cellular processing of radiation-induced damage to DNA by enzymes may result in a return to normal sequence and structure, or processing may fail or may cause alterations in DNA that lead to lethality or heritable changes (mutations and chromosomal aberrations) in surviving cells (BEIR VII, 2006).

Nationwide surveys have been performed to assess the background radiation levels for some cities of Turkey, especially at the northern parts which were affected from the Chernobyl accident (Yarar *et al.,* 2005; Dogru *et al.,* 2005; Merdanoglu *et al.,* 2006; Kilic *et al.,* 2008; Erees *et al.,* 2006; Gurler *et al.,* 2007; Kam *et al.,* 2007; Bozkurt *et al.,* 2007; Osmanlioglu *et al.,* 2007; Sahin *et al.,* 2008; Degerlier., *et al.,* 2008; Kam *et al.,* 2009; Taskin *et al.,* 2009). Therefore, the aim of this study is to determine the activity levels of the radionuclide in soil and the health risks due to natural radiation sources in the important industrial city of Yalova, northwestern Turkey.

MATERIALS & METHODS

As a research region, city of Yalova with population of 202.531 and the area of about 850 km^2 was selected. The city is located at between +40° 41' E and +40° 31' E coordinates and between +28° 46' N and +29° 33' N coordinates, and average of 2 meter above the sea level, shown in Fig.1 with the neighbors. The city is located at the Northwestern Anatolia region including significant population and economic activities of Turkey. In terms of geography, a large part of the region consists of flat areas in the coastal sides of the city except for the hilly areas in Armutlu distinct including mountain of Daz whose highest point of 921 m. towards the east sides of the distinct. The soil structure consists of clay and sand in the large part of the region. The region lies along the North Anatolian Fault, as shown in Fig.2 (Yilmaz *et al.,* 2005). The earthquake in 1999 has damaged so drastically to this city. Lots of the buildings were collapsed during earthquake or taken down after that.

Activity concentrations of radionuclide in soil and the outdoor gamma dose rates (terrestrial and cosmic) have been investigated by collecting soil samples and reading of gamma dose rates in air, in the Yalova. Table 1 presents the number of outdoor gamma measurements and the soil samples by the catchment area with the population. In order to determine the outdoor gamma

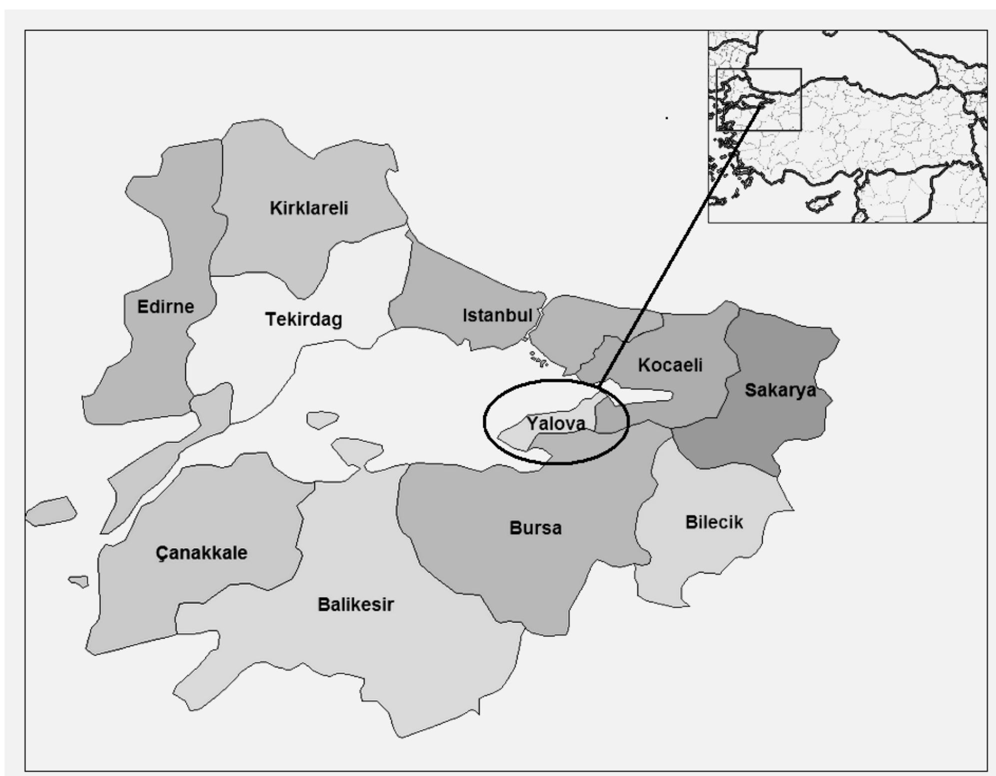

Fig. 1. The city of Yalova and its' neighbours

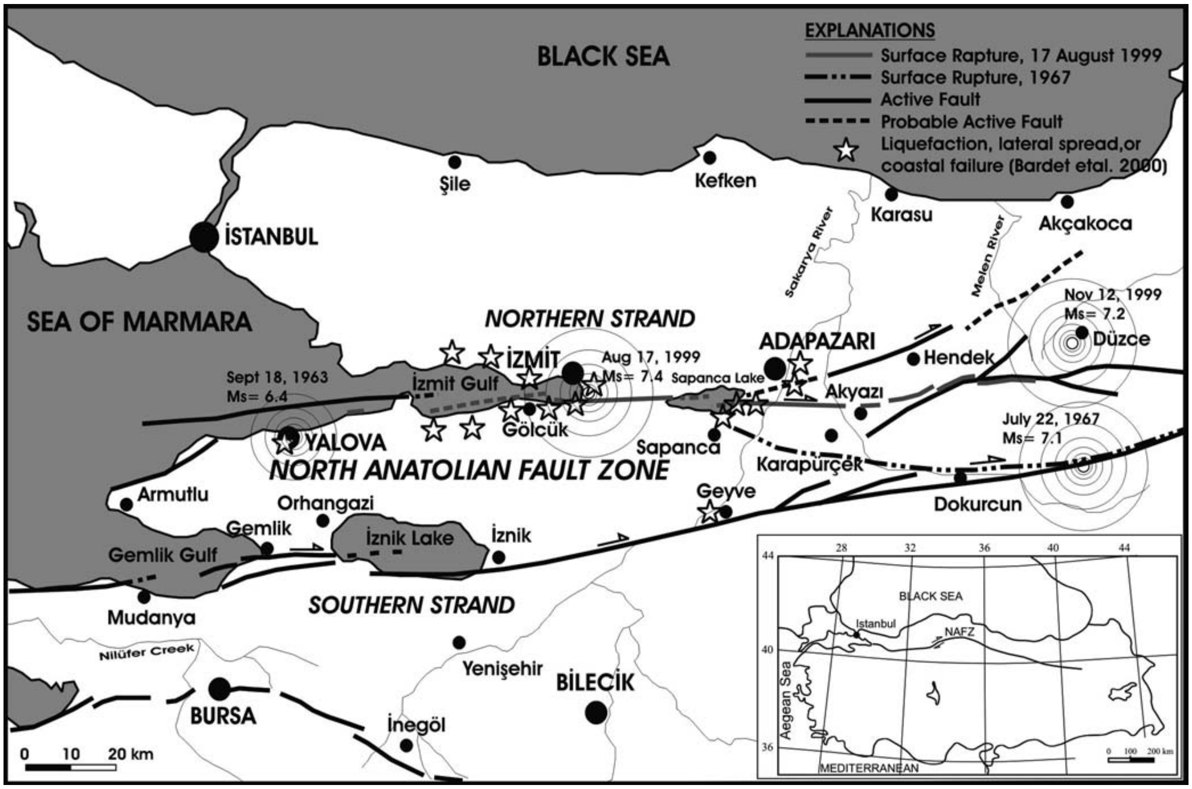

Fig. 2. Fault map of the study area, showing the location of major recent earthquakes and liquefaction, lateral spread, or coastal failure (Yilmaz *et al.*, 2005)

Table 1. The number of gamma readings and the soil samples taken by the catchment area

Distinct	Number of gamma readings		Number of soil samples		Catchment area		Population	
	n	%	n	%	A (km^2)	%	P	%
Yalova (Center)	**10**	20	**9**	22,5	**177**	21	**114.054**	56
Termal	**4**	7,5	**3**	7,5	**50**	6	**5.086**	3
Cinarcik	**10**	20	**7**	17,5	**173**	20	**25.892**	13
Armutlu	**13**	27,5	**11**	27,5	**207**	24	**8.025**	4
Ciftlikkoy	**7**	15	**6**	15	**129**	15	**26.239**	13
Altinova	**5**	10	**4**	10	**114**	13	**23.235**	11
Region	**48**	100	**40**	100	**850**	100	**202.531**	100

dose rates, Yalova was divided to 48 geographic areas. Each geographic area served as a sampling station. For each sampling station, measurements were taken at three different locations. The mean of the three measurements was calculated and appointed as the outdoor gamma dose rate of the sampling station. The coordinates of the readings were determined by Global Positioning System (GPS). MapInfo 6.0 software was used for plotting the data in diagrams. The outdoor gamma dose rates were measured by Eberline smart portable device (ESP-2) connected with an SPA-6 model plastic scintillation detector. Measurements were taken in air for two minutes at 1 m above the ground and the gamma dose rates were recorded as μR/h and then converted to nGy/h using the conversion factor of 8.7 nGy/μR (1). The annual effective dose equivalent (AEDE) was calculated by using the following equation.

AEDE = ADRA x DCF x OF x T (1)

where ADRA, DCF, OF are absorbed dose rate in air (nGy/h), dose conversion factor (0.7 Sv/Gy), outdoor occupancy factor (0.2), respectively, and T is the time (8760 h/y). Excess lifetime cancer risk (ELCR) was calculated by using equation (2)

ELCR = AEDE x DL x RF (2)

where DL is duration of life (70 year) and RF is risk factor (1/Sv), fatal cancer risk per Sievert. For stochastic effects, ICRP 103 uses values of 0.057 for the public (ICRP, 2007).

In order to determine soil radionuclide's' activity concentration, 40 sampling stations were selected. Soil samples were obtained from uncultivated locations that were close to settlements. Open, flat and undisturbed geographical locations which had good water permeability were selected as the sampling points. The first 10 cm of topsoil was taken, foreign bodies were removed and the remaining soil was placed in clean, sealed and labeled bags. The samples were dried at 60 ^{0}C for 48 h, grained, passed through 2 mm sieves and placed in Marinelli type beakers. The samples were kept one month before the analysis at airtight condition to allow secular equilibrium between thorium and radium and their decay products. The system was calibrated using standard mixtures of gamma emitting isotopes in Marinelli beakers. Each sample was placed in gamma spectroscopy and was counted for 50 000 s using a gamma spectroscopy device connected to a coaxial HPGe detector, Canberra. The activities of the samples were determined using the total net counts under the selected photopeaks, the measured photopeak efficiency, gamma intensity and weight of the samples. After correcting for background and Compton contribution, the activity concentrations of ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K and ^{137}Cs were determined. The ^{238}U and ^{232}Th were calculated assuming secular equilibrium was established with their decay products [^{238}U series: ^{226}Ra (186.0 keV), ^{214}Pb (351.9 keV) and ^{214}Bi (609.2 keV); ^{232}Th series: ^{228}Ac (911 keV), ^{208}Tl (583.1 keV)]. External terrestrial gamma dose rate was calculated from the concentrations of the radionuclide in soil. Based on the radioactivity levels of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs, gamma absorbed dose rate in air (ADRA) in nGy/h at 1 m above the ground level was calculated by using equation (3) (UNSCEAR, 2000).

ADRA = $0.461A_{Ra}$ x $0.623A_{Th}$ x $0.0417A_{K}$ x $0.1243A_{Cs}$ (3)

where A_{Ra}, A_{Th}, A_{K} and A_{Cs} are activity concentrations (Bq/kg) of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs, respectively, in soil sample. The analyses were carried out in the laboratory of Cekmece Nuclear Researches and Training Centre (CNAEM) Radioactivity Analysis Department.

RESULTS & DISCUSSIONS

Outdoor gamma dose rates were determined in 48 locations and soil samples were taken from 40 sampling stations. It has been observed that the average absorbed gamma dose rate was 84.30 nGy/h for the region. The readings ranged from 36.11 to 148.77 nGy/h. These values consist of terrestrial and cosmic radiations together. The measured outdoor gamma exposure dose rates (GEDR) in µR/h and absorbed gamma dose rates in air (ADRA) in nGy/h are presented for each distinct of the Yalova in Table 2. It has been seen that the maximum determined dose rate was at the Armutlu distinct, but the distinct of Ciflikkoy has highest average dose rate in the region. The map of measured outdoor gamma exposure dose rates (GEDR) in µR/h is also given in Fig. 3.

The mean ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K, ^{137}Cs, ^{7}Be, and ^{235}U activities with their ranges were determined as 26.87 (3.8-43.9) Bq/kg, 22.36 (8.3-41) Bq/kg, 17.95 (8.5-37.3) Bq/kg, 2.53 (0.5-13.4) Bq/kg, 419.32 (197.1-950.0)

Table 2. The outdoor gamma measurements

	GEDR (Gamma Exposure Dose Rate) (µR/h)			ADRA (Absorbed Dose Rate in Air) (nGy/h)		
Distinct	**Minimum**	**Maximum**	**Mean**	**Minimum**	**Maximum**	**Mean**
Yalova (Center)	8,75	10,90	9,78	76,13	94,83	85,12
Termal	7,95	9,60	7,95	69,17	83,52	69,17
Cinarcik	7,20	10,10	8,79	62,64	87,87	76,45
Armutlu	4,15	17,10	10,02	36,11	148,77	87,15
Ciftlikkoy	11,80	12,85	12,30	102,66	111,80	107,01
Altinova	9,10	9,70	9,30	79,17	84,39	80,91
Region	4,15	17,10	10,02	36,11	148,77	84,30

Fig. 3. The Map of Measured Absorbed Gamma Dose Rates in Air

Bq/kg, 2.11 (0.9-6.8) Bq/kg, 1.40 (0.6-2.6) Bq/kg, respectively, in soil of the region. The determined activity levels for each distinct in the region are also given in Table 3. It was observed that the mean ^{238}U, ^{232}Th, ^{226}Ra, ^{40}K, and ^{235}U activities, main contributors of external gamma exposure, were the highest at the distinct of Ciflikkoy. Concentrations of this radionuclide in soil mainly depend on the geological structures of the regions. In addition, ^{137}Cs and ^{7}Be activities have been seen at the highest levels in Cinarcik distinct. The main reason for accumulation of this radionuclide in soil is the falling out. The maps of activity concentrations of radionuclide, ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs are also given in Fig. 4, Fig. 5 Fig 6 and Fig.7, respectively. The maps indicated that gamma dose rates were highly correlated with the activities of this radionuclide.

The average dose rates due to terrestrial and cosmic radiations for the city of Yalova with its' distinct are given at the Table 4. The average terrestrial gamma dose rate was calculated as 48.89 nGy/h for the region by using the activities of radionuclide in soil in equation (3). The highest average terrestrial dose rate has been seen in the distinct of the Ciftlikkoy. Terrestrial gamma dose rates varied considerably within the study area, even among the closest regions. This variation is associated with the radionuclide activity concentrations of the soil. It has been observed that there was a strong correlation between calculated terrestrial dose rates and measured dose rates in all distinct.

The average dose rate due to cosmic radiations was calculated as 35.40 nGy/h by subtracting calculated terrestrial gamma dose rates from the measured rates in air. Cosmic gamma dose rates measured in the regions mainly depend on altitude and geomagnetic latitude of the regions. Therefore, there is no significant changes in cosmic radiation levels between different distinct in the region.

Health effects of ionizing radiations in the environment of Yalova have been investigated by determining effective biological radiation doses and cancer risks caused by the background radiation exposures. Annual effective doses and lifetime cancer risks due to outdoor cosmic and terrestrial radiations are presented in Table 5. Annual effective doses due to terrestrial and cosmic radiations, were determined as 59.96 nSv and 43.42 nSv, respectively, with the total of 84.30 nSv for the region, using equation (1). The mean estimated cancer risk value due to outdoor gamma radiations, using equation (2) with the latest risk factor of ICRP, was found to be 0.042×10^{-2} for the region; however, the risk value can change depending on methods and risk factors chosen (ICRP 103, 2007).

There is a list of studies done in the close cities to the region in Table 6. It has been observed that average ^{238}U, ^{232}Th, ^{226}Ra, activities in soil of the region was lower than the close cities and worldwide average depending on geologic structure of the region. ^{40}K activity level in soil of the region has been determined higher than worldwide average and between

Table 3. Radionuclide activity concentrations in soil

	U-238 (Bq/kg)		Th-232 (Bq/kg)		Ra-226 (Bq/kg)		K-40 (Bq/kg)		Cs-137 (Bq/kg)		Be-7 (Bq/kg)		U-235 (Bq/kg)	
Distinct	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Yalova														
(Center)	20,85	(17,5-24,2)	34,15	(26,9-41,4)	22,30	(17,5-27,1)	323,50	(231,5-415,5)	2,40	(1,8-2,4)	1,30	(1,1-1,4)	1,45	(1,3-1,6)
Termal	15,03	(13,5-16,2)	24,56	(21,5-27,7)	19,06	(16,5-21,6)	310,00	(223.6-403.8)	3,22	(1,2-5,5)	1,87	(1,4-2,2)	1,13	(1,0-1,2)
Cinarcik	14,25	(13-15,3)	23,23	(22,1-24,3)	22,23	(11,5-28,2)	432,98	(300,4-591,9)	5,13	(0,5-13,4)	3,08	(2,3-3,9)	1,20	(1,1-1,4)
Armutlu	20,19	(8,6-29,1)	27,18	(3,8-42,8)	27,24	(8,3-41)	561,84	(214-950)	2,40	(0,7-8,1)	2,31	(0,9-6,8)	1,32	(0,6-1,8)
Ciftlikkoy	37,30	(35,3-38,6)	43,90	(40,2-44,9)	28,20	(18,5-32,2)	651,70	(480,8-751,7)	1,90	(0,8-2,9)	2,30	(1,3-2,9)	2,40	(2,1-2,6)
Altinova	14,50	(11,5-16,6)	24,60	(19,6-23,7)	25,00	(22-29)	463,20	(413,2-458,6)	0,70	(0,6-0,8)	1,50	(1,3-1,8)	0,90	(0,7-1,1)
Region	17,95	(8,5-37,3)	26,87	(3,8-44,9)	22,36	(8,3-41)	419,32	(197,1-950)	2,53	(0,5-13,4)	2,11	(0,9-6,8)	1,40	(0,6-2,6)

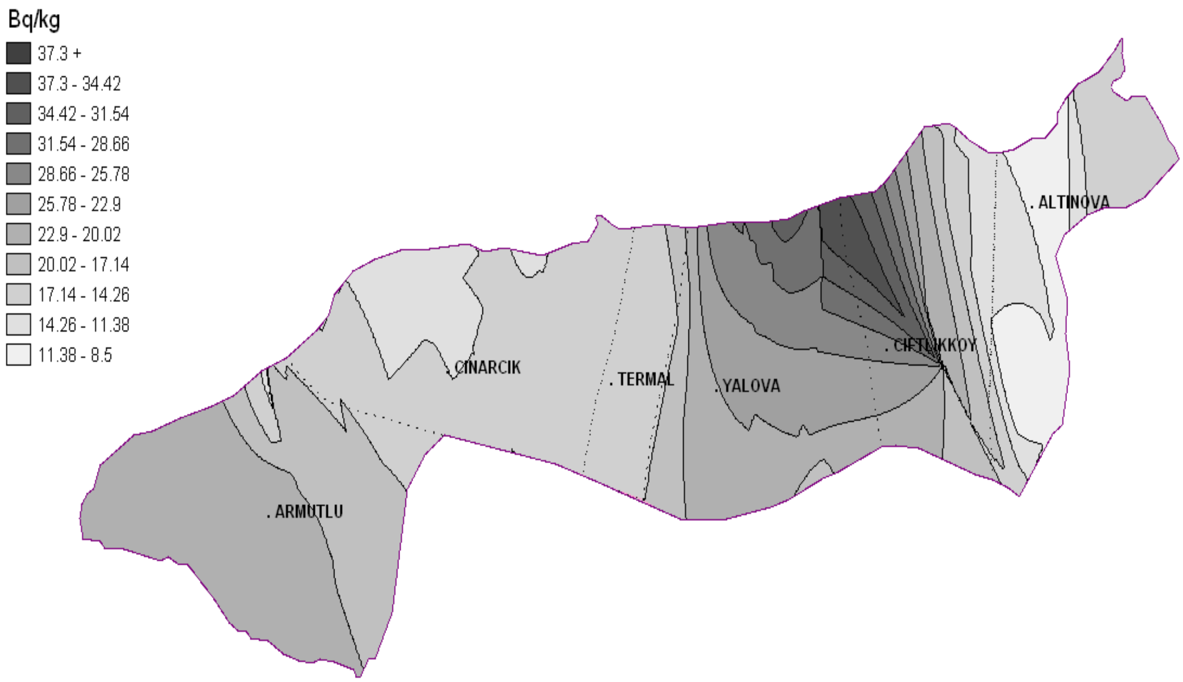

Fig. 4. The map of ^{238}U radionuclide activity concentrations

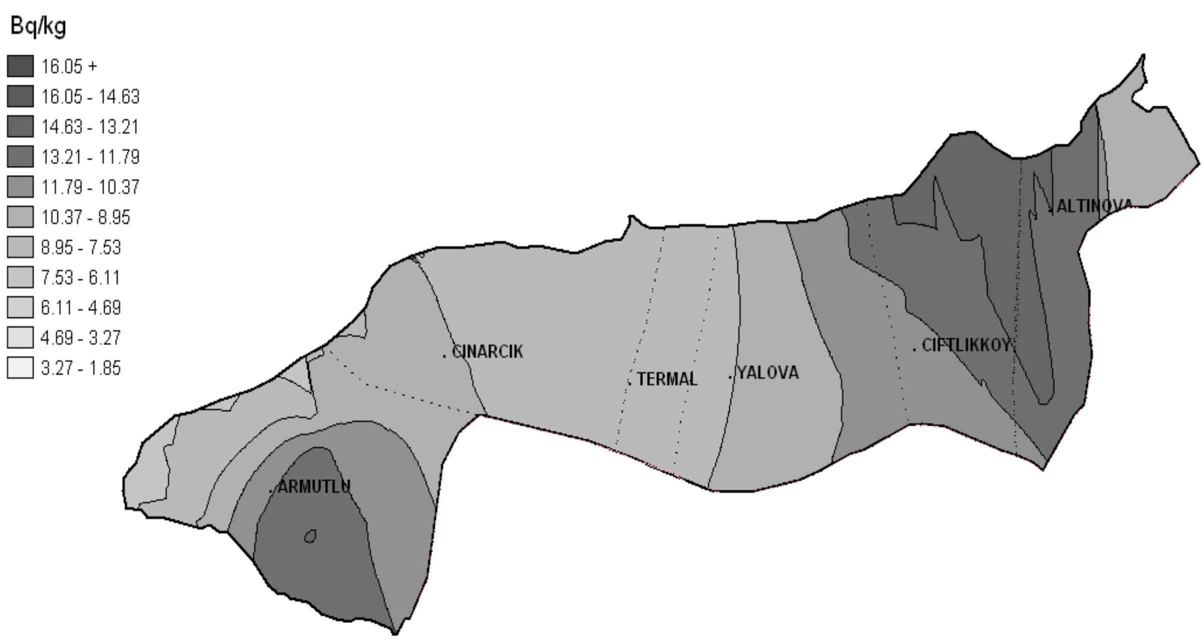

Fig. 5. The map of ^{232}Th radionuclide activity concentrations

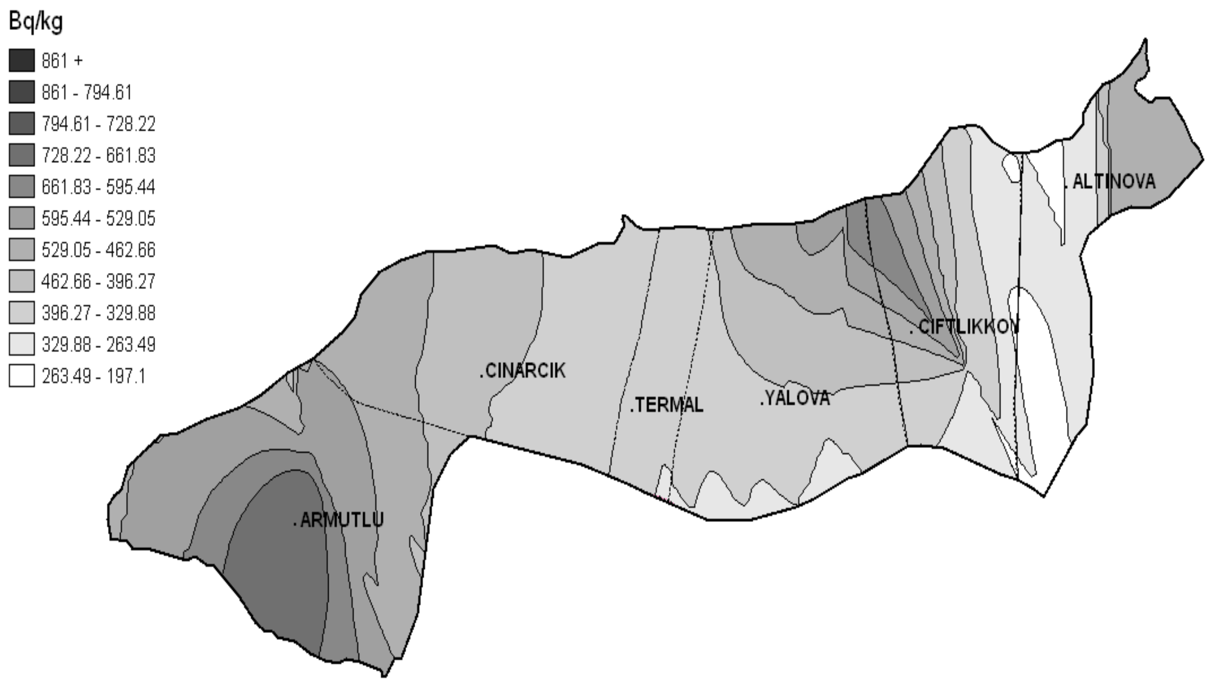

Fig. 6. The map of ^{40}K radionuclide activity concentrations

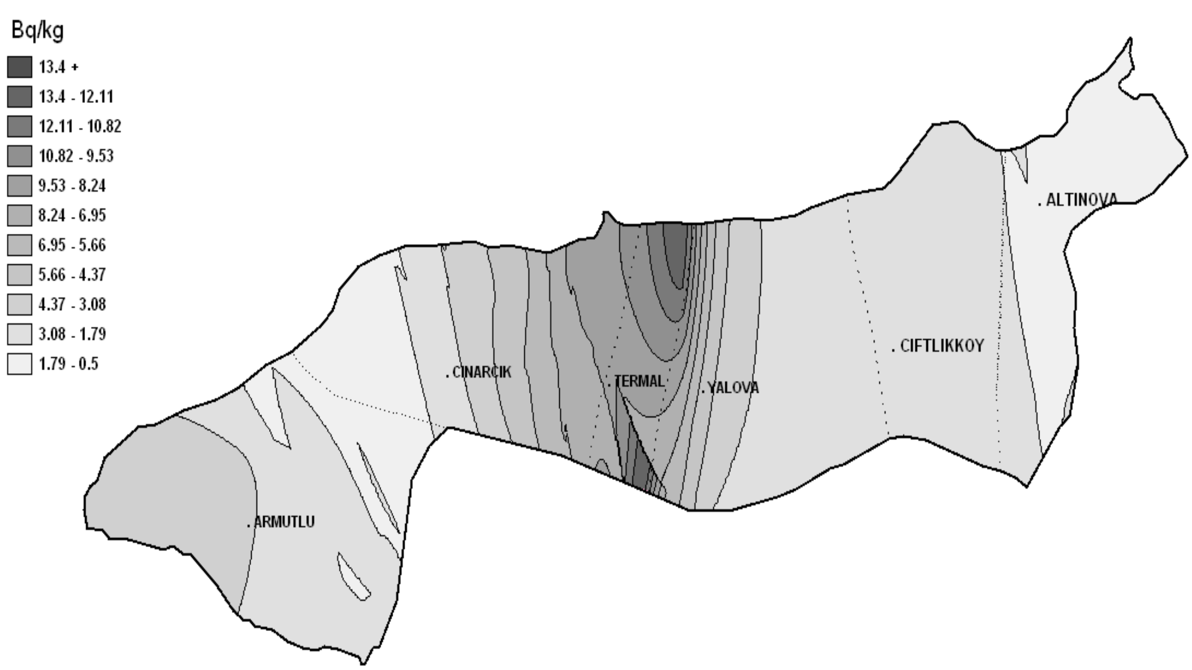

Fig. 7. The map of ^{137}Cs radionuclide activity concentrations

Table 4. Absorbed dose rates in air (ADRA)

Distinct	ADRA (Absorbed Dose Rate in Air) (nGy/h)		
	Terrestrial	Cosmic	Total
Yalova (Center)	45,34	39,77	85,12
Termal	37,42	31,75	69,17
Cinarcik	43,41	33,04	76,45
Armutlu	53,22	33,93	87,15
Ciftlikkoy	67,73	39,28	107,01
Altinova	46,25	34,66	80,91
Region	48,89	35,40	84,30

Table 5. Annual Effective Dose Equivalents and Lifetime Cancer Risk

Distinct	Outdoor AEDE (Annual Effective Dose Equivalent) (nSv/y)			Lifetime Cancer Risk (%)
	Terrestrial	Cosmic	Total	
Yalova (Center)	55,61	48,78	104,39	0,042
Termal	45,89	38,94	84,82	0,034
Cinarcik	53,24	40,52	93,76	0,038
Armutlu	65,27	41,61	106,87	0,043
Ciftlikkoy	83,06	48,18	131,24	0,053
Altinova	56,72	42,50	99,23	0,040
Region	59,96	43,42	103,38	0,042

Table 6. Activity Concentrations of Radionuclides and Absorbed Dose Rates in Air (ADRA) in close cities to region and worldwide averages

Reference	Location	Activity Concentrations of Radionuclides (Bq/kg)					ADRA (Absorbed Dose Rate in Air) (nGy/h)	
		U-238	Th-232	Ra-226	K-40	Cs-137	Terrestrial	Terrestrial + Cosmic
Persent Study	**Yalova**	18 (9-37)	27 (4-45)	22 (8-41)	419 (197-950)	3 (1-13)	49	84 (36-149)
Taskin et al 2009	**Kirklareli**	28 (5-73)	40 (7-151)	37 (5-111)	667 (87-2084)	8 (1-38)	71	118 (28-283)
Karahan et al 2000	**Istanbul**	21	37	-	342	(1.8-81)	49	60
UNSCEAR 2000	**Worldwide**	35 (16-110)	30 (11-64)	35 (17-60)	400 (140-850)	-	54	57 (18-93)

the levels of these close cities, reasonably. ^{137}Cs is spread to the atmosphere through nuclear activities. Most of the fallout radiation accumulates in the soil (UNSCEAR, 1982). Turkey has been affected by the Chernobyl nuclear power accident in 1986 as other countries. Studies conducted after the accident pointed out to ^{137}Cs accumulation particularly at the north coast of Turkey and Thrace (Gokmen *et al.*, 1996). In this study, the average ^{137}Cs concentration was found to be 2.53 Bq/kg 14 years after the accident. These values are lower that of the close cities of the region, as can be seen in Table 6. Additionally, it has been seen that the measured average gamma dose rate in the region is found to be in good agreement with the values determined in other cities of Turkey and the worldwide averages (UNSCEAR, 2000; Yarar, Y., *et al.*, 2005; Kam E. *et al.*, 2007; Osmanlioglu A., *et al.*, 2007; Bozkurt A., *et al.*, 2007; Degerlier M., *et al.*, 2008; Kam E., *et al.*, 2009; Taskin, H., *et al.*, 2009).

CONCLUSION

Background radiation investigations, major issue of environmental monitoring studies, have been done all over the world in order to determine soil radioactivity structure and to evaluate the health risks. This study determined that the average soil activity concentrations of Yalova were within the worldwide range, although some extreme values had been determined. Moreover, it was observed that the average activities of ^{238}U, ^{232}Th, ^{226}Ra radionuclide in soil of Yalova were lower than the worldwide averages; whereas ^{40}K activity level in soil was higher. At the low levels of ^{137}Cs activity concentration has been determined in the region 14 years after the Chernobyl accident. Annual effective gamma doses and the lifetime risk of cancer values were determined as higher than the world's averages in terms of health effects of background radiations in the Yalova.

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