

# MEASUREMENT OF THE TERRESTRIAL AND ANTHROPOGENIC RADIONUCLIDE CONCENTRATIONS IN BAFRA KIZILIRMAK DELTA (BIRD SANCTUARY) IN TURKEY

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In this study, the activity concentrations of terrestrial and anthropogenic radionuclides in the soil samples collected from Bafra Kızılırmak Delta were measured by using gamma spectrometry with an NaI(Tl) detector. The average values of activity concentrations of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K were found to be  $37.2 \pm 2.8$ ,  $33.7 \pm 3.1$  and  $413.0 \pm 59.8$  Bq kg<sup>-1</sup>, respectively. <sup>137</sup>Cs was also measured in some samples. It has a mean value of  $13.8 \pm 1.0$  Bq kg<sup>-1</sup>. From the activity concentrations, the absorbed gamma dose rates in outdoor and the corresponding annual effective dose rates and external hazard index ( $H_{ex}$ ) were estimated.

## INTRODUCTION

Environmental radiation is composed of both natural and anthropogenic (or artificial) radiation. Natural radiation mainly arises from naturally occurring radionuclides of terrestrial origin. Terrestrial radionuclides include mainly radionuclides in the <sup>238</sup>U and <sup>232</sup>Th decay series and <sup>40</sup>K<sup>(1)</sup>. The main sources of anthropogenic radiation are radionuclides that can be produced and/or released in medical facilities; military-based nuclear weapons, nuclear accidents at nuclear reactors and discharges of radioactive waste of nuclear fuel from the nuclear installations. As a result of radioactive fallout from the Chernobyl nuclear reactor accident occurred in 1986, food and environmental samples such as water, food, milk, soil, etc., in especially Thrace and Black Sea regions of Turkey were contaminated with long-lived anthropogenic radionuclides such as radiocesium and radiostrotrium<sup>(2)</sup>.

Human beings are exposed to radiation from both natural and anthropogenic radionuclides in the environment. External exposures outdoors result from the terrestrial radionuclides existing at different levels related to the types of rock in all soil. Therefore, it is important to determine the activity concentrations of these radionuclides in soil samples. On the other hand, the measurement of the average outdoor terrestrial gamma dose rate in air is also important for the radiological protection purposes and implementing some precautions.

Recently, there are several related studies to determine the soil radioactivity, terrestrial gamma dose rate and annual effective dose (AED) rate in the literature<sup>(3–23)</sup>. However, there is no study related to the

activity concentrations of the radionuclides in soil samples collected from the Bafra Kızılırmak Delta (bird sanctuary) in the literature. The objective of the study is to determine the activity concentrations of terrestrial and anthropogenic radionuclides and evaluate the outdoor gamma dose rate and corresponding AED from the external exposure.

## Geology of Kızılırmak Delta

Kızılırmak Delta is located in the central Black Sea region of Turkey (Figure 1). It is in the region between north latitudes 41.30N–41.44N and east longitudes 35.35E–36.07E. The delta owns its name from Kızılırmak river which is the longest river in Turkey. Kızılırmak Delta was evolved through quaternary. In addition to eustatic moves, tectonic moves had an effect during its forming. The delta covers a surface area of 564 km<sup>2</sup> and it is the third biggest delta in Turkey. It is one of the most important wetland complexes with its rich biodiversity and critical habitat for globally endangered bird species<sup>(24)</sup>. There are 321 different bird types in the delta and it is an immigration area for birds. It is also one of the most productive agricultural deltas in Turkey. The delta contains mainly alluvial and clay soil. This kind of soil consists of kaolinite which is waterproof.

## EXPERIMENTAL METHODS

### Sample collection and preparation

The survey area is in the region between 36.02'00"E–36.06'15"E and 41.36'34"N–41.40'02"N. To measure the terrestrial and anthropogenic radioactivity in soil

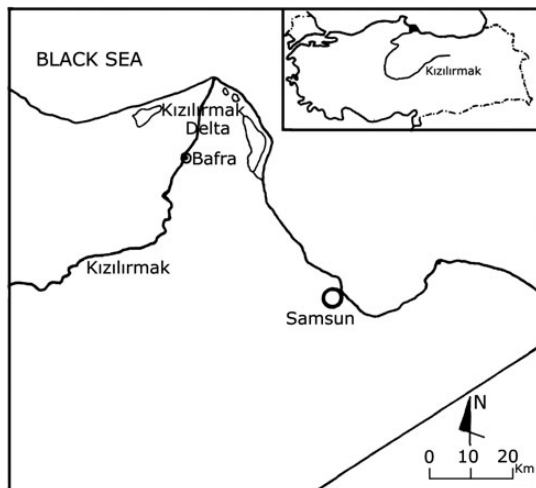


Figure 1. Location of Kızılırmak Delta.

samples collected at 20-cm depth level from 30 different stations. After stones and other foreign bodies were removed from the soil samples, the samples were oven dried at 105°C for 24 h to remove the moisture content. In the next step, the samples were pulverised and sieved through a 0.1-mm mesh to be homogenised. After this process, the soil samples were packed in a standard plastic containers (5.5 cm × 6.5 cm diameter), weighed and hermetically sealed and then stored 4 weeks before counting by gamma spectrometry to achieve secular equilibrium between <sup>226</sup>Ra and its short-lived decay products.

#### Counting by gamma spectrometry system

The measurements of the radioactivity concentrations of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K in the soil samples were carried out using a 7.62 × 7.62 cm NaI(Tl) detector (Ortec-905-4). Energy resolution of the detector measured in terms of full-width at half-maximum is 46 keV at 661.8 keV <sup>137</sup>Cs. The light decay time constant for an NaI(Tl) crystal is ~0.23 μs. Typical charge-sensitive preamplifiers translate this into an output voltage pulse with a increase in time of ~0.5 μs.

Efficiency calibration of the system in the 186.2–2614.4-keV energy range was done using the well-known reference materials of IAEA: RGU-1, RGTh-1 and RGK-1<sup>(25)</sup>. Each sample was then counted for ~24 h in the same source-to-detector geometry as used for the determination of the efficiency calibration. All samples were counted while the detector was placed in the table top lead shield (Lead Shield G-5 made Ortec). After counting, the environmental gamma background measurements obtained at the laboratory with an empty container placed in the detector with same time that elapsed for the prior counting. MAESTRO-32

MCA software is used for spectrum display, analysis and system adjustment and calibration prior to sample measurement. The activity concentrations of <sup>238</sup>U and <sup>232</sup>Th were determined using the gamma-ray line of the 1764.5 keV from <sup>214</sup>Pb and the gamma-ray line of the 2614.4 keV from <sup>208</sup>Tl, respectively, assuming secular equilibrium in the <sup>238</sup>U and <sup>232</sup>Th decay series. The activity concentration of <sup>40</sup>K and <sup>137</sup>Cs was measured directly by their own gamma-ray line at 1460.8 and 661.7 keV, respectively. However, the activity concentrations of <sup>137</sup>Cs were corrected for due to the interference of 609-keV gamma photopeak from <sup>214</sup>Pb in the 661.7-keV gamma photopeak from <sup>137</sup>Cs.

#### Estimation of air-absorbed dose rate and corresponding AED

Two different formulas were used to estimate the outdoor air-absorbed dose rates (nGy h<sup>-1</sup>) at 1 m above from the ground due to the activity concentrations of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K in the soil samples. If the sample does not contain <sup>137</sup>Cs concentration<sup>(26)</sup>:

$$D = 0.463 \cdot A_U + 0.604 \cdot A_{Th} + 0.0417 \cdot A_K \quad (1)$$

and if the sample contains <sup>137</sup>Cs concentration<sup>(27)</sup>:

$$D = 0.470 \cdot A_U + 0.572 \cdot A_{Th} + 0.0421 \cdot A_K + 0.156 \cdot A_{Cs} \quad (2)$$

where  $D$  is the absorbed dose rate (nGy h<sup>-1</sup>) and  $A_U$ ,  $A_{Th}$ ,  $A_K$  and  $A_{Cs}$  are the activity concentrations of <sup>238</sup>U, <sup>232</sup>Th, <sup>40</sup>K and <sup>137</sup>Cs in Bq kg<sup>-1</sup>, respectively. The corresponding AED in units of mSv per y was estimated as follows<sup>(1)</sup>:

$$AED = D \times DCF \times OF \times T \quad (3)$$

where  $D$  is the outdoor absorbed gamma dose rate given Eq (1) and (2), DCF, OF and T are dose conversion factor (0.7 Sv Gy<sup>-1</sup>), outdoor occupancy factor (0.2) and time (8760 h y<sup>-1</sup>), respectively<sup>(1)</sup>.

#### External hazard index

$H_{ex}$  can be calculated from the activity concentration values as follows<sup>(27)</sup>:

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

where  $A_U$ ,  $A_{Th}$  and  $A_K$  are the activity concentrations of <sup>238</sup>U, <sup>232</sup>Th and <sup>40</sup>K in Bq kg<sup>-1</sup>, respectively. If this value is less than unity, then the radiation hazard is insignificant.

**Table 1.** The activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  were measured in the soil samples of Kızılırmak Delta.

Sample no.	Activity concentration ( $\text{Bq kg}^{-1}$ )			
	$^{238}\text{U}$	$^{232}\text{Th}$	$^{40}\text{K}$	$^{137}\text{Cs}$
1	37.1 ± 4.1	32.1 ± 1.4	402.2 ± 14.1	<MDA
2	33.5 ± 7.8	32.2 ± 1.4	407.9 ± 13.8	<MDA
3	20.4 ± 1.5	24.8 ± 1.4	231.8 ± 14.0	<MDA
4	20.4 ± 5.9	34.4 ± 1.4	293.8 ± 13.8	7.9 ± 1.6
5	35.1 ± 3.1	32.2 ± 1.1	289.2 ± 11.6	<MDA
6	42.8 ± 5.4	37.6 ± 1.5	246.4 ± 14.6	<MDA
7	57.2 ± 3.7	34.9 ± 1.5	532.7 ± 16.8	<MDA
8	57.1 ± 2.5	43.4 ± 9.7	400.0 ± 12.8	19.2 ± 4.6
9	47.2 ± 3.7	37.1 ± 1.2	1056.9 ± 12.0	<MDA
10	67.3 ± 3.5	56.9 ± 2.3	1247.2 ± 14.8	<MDA
11	56.5 ± 3.6	<MDA	1161.8 ± 15.7	<MDA
12	39.6 ± 2.0	41.4 ± 4.3	538.2 ± 8.2	10.9 ± 0.9
13	49.8 ± 3.3	80.1 ± 9.9	1189.8 ± 14.3	<MDA
14	35.3 ± 5.1	36.0 ± 1.1	561.5 ± 12.3	<MDA
15	40.3 ± 2.2	30.0 ± 1.1	291.4 ± 10.6	20.3 ± 1.5
16	21.8 ± 1.7	15.4 ± 1.0	160.1 ± 8.1	12.1 ± 1.0
17	38.2 ± 5.5	38.1 ± 1.4	372.3 ± 13.8	<MDA
18	30.6 ± 2.5	28.6 ± 1.3	207.4 ± 13.0	<MDA
19	21.0 ± 2.7	22.4 ± 0.9	182.0 ± 8.9	<MDA
20	57.0 ± 3.0	31.4 ± 7.5	110.3 ± 8.4	11.3 ± 1.1
21	30.8 ± 2.5	16.8 ± 1.0	215.1 ± 10.0	18.8 ± 1.2
22	32.2 ± 5.4	20.2 ± 1.0	143.1 ± 20.5	17.4 ± 2.4
23	52.7 ± 14.2	36.6 ± 1.2	345.1 ± 11.8	<MDA
24	39.1 ± 3.9	32.1 ± 1.1	341.8 ± 10.7	6.0 ± 1.3
25	3.2 ± 0.3	3.7 ± 0.1	32.6 ± 1.2	<MDA
26	35.8 ± 3.5	34.8 ± 1.3	347.4 ± 12.5	<MDA
27	37.4 ± 3.6	27.8 ± 1.2	351.8 ± 12.3	<MDA
28	2.6 ± 0.3	4.3 ± 1.2	33.0 ± 1.3	<MDA
29	42.0 ± 3.0	28.6 ± 1.1	332.7 ± 11.4	<MDA
30	33.6 ± 3.3	83.8 ± 4.5	364.5 ± 14.4	<MDA
Min	2.6	<MDA	32.6	<MDA
Max	67.3	83.8	1247.2	20.3
Average	37.2	33.7	413.0	13.8
Standard deviation	15.1	17.2	327.6	5.3

MDA, minimum detectable activity.

## RESULTS AND DISCUSSION

The activity concentration values of  $^{238}\text{U}$ ,  $^{232}\text{Th}$ ,  $^{40}\text{K}$  and  $^{137}\text{Cs}$  measured in the soil samples are given in Table 1. The  $\pm$  values represents 1 standard deviation due to counting errors. As shown in Table 1, the average activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  are measured to be  $37.2 \pm 2.8 \text{ Bq kg}^{-1}$  (range:  $2.6 \pm 0.3$ – $67.3 \pm 3.5 \text{ Bq kg}^{-1}$ ),  $33.7 \pm 3.1 \text{ Bq kg}^{-1}$  [range: minimum detectable activity (MDA)  $83.8 \pm 4.5 \text{ Bq kg}^{-1}$ ] and  $413.0 \pm 59.8 \text{ Bq kg}^{-1}$  (range:  $32.6 \pm 1.2$ – $1247.2 \pm 4.8 \text{ Bq kg}^{-1}$ ), respectively. The population-weighted world averages of these nuclides are  $33 \text{ Bq kg}^{-1}$  (range:  $16$ – $110 \text{ Bq kg}^{-1}$ ) for  $^{238}\text{U}$ ,  $45 \text{ Bq kg}^{-1}$  (range:  $11$ – $64 \text{ Bq kg}^{-1}$ ) for  $^{232}\text{Th}$  and  $420 \text{ Bq kg}^{-1}$  (range:  $140$ – $850 \text{ Bq kg}^{-1}$ ) for  $^{40}\text{K}$ <sup>(1)</sup>. The  $^{238}\text{U}$  average concentration measured in the samples is statistically the same as the world average within the

confidence level of 95%. The  $^{232}\text{Th}$  average concentration is less than the world average but it is within the range. The average activity concentration of  $^{40}\text{K}$  is statistically indistinguishable from the world average.  $^{137}\text{Cs}$  was detected in 9 samples of the total 30 samples. In 21 samples, the concentration activity of  $^{137}\text{Cs}$  is below the MDA which is  $\sim 0.5 \text{ Bq kg}^{-1}$ . The activity concentrations of  $^{137}\text{Cs}$  measured in nine soil samples varied from  $6.0 \pm 1.3$  to  $20.3 \pm 1.5 \text{ Bq kg}^{-1}$  with a mean value of  $13.8 \pm 1.0 \text{ Bq kg}^{-1}$ .

The absorbed gamma dose rate in air 1 m above the ground was estimated for each soil sample using the activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  given in Table 1. The estimated values of the absorbed gamma dose rate ( $D$ ) are given in the second column of Table 2. From Table 2, the absorbed gamma dose rates varied from  $5.1 \pm 0.3$  to  $122.3 \pm 8.3 \text{ nGy h}^{-1}$  with an average value of  $54.1 \pm 4.6 \text{ nGy h}^{-1}$ .

**Table 2.** The absorbed gamma dose rate ( $D$ ), the corresponding AED (AED) and external hazard index ( $H_{\text{ex}}$ ).

Sample no.	$D$ (nGy h <sup>-1</sup> )	AED (μSv y <sup>-1</sup> )	$H_{\text{ex}}$
1	53.9	66.1	0.31
2	52.5	64.4	0.30
3	34.5	42.3	0.20
4	43.0	52.8	0.25
5	48.2	59.2	0.28
6	53.4	65.5	0.31
7	70.3	86.2	0.40
8	70.0	85.8	0.40
9	88.9	109.1	0.49
10	118.4	145.2	0.66
11	55.8	74.2	0.36
12	68.3	83.8	0.39
13	122.3	150.0	0.69
14	62.1	76.2	0.35
15	49.4	60.6	0.29
16	26.3	32.2	0.15
17	56.8	69.7	0.33
18	40.5	49.7	0.24
19	31.2	38.2	0.18
20	50.4	61.9	0.30
21	33.6	41.2	0.19
22	33.4	40.9	0.19
23	61.5	75.4	0.36
24	52.3	64.1	0.30
25	5.1	6.3	0.03
26	52.6	64.5	0.30
27	49.2	60.3	0.28
28	5.2	6.4	0.03
29	51.0	62.6	0.29
30	82.7	101.5	0.49
Min	5.1	6.3	0.03
Max	122.3	150.0	0.69
Average	54.1	66.5	0.31
Standard deviation	25.9	31.8	0.15

The population-weighted world average of the outdoor absorbed dose rate in air is 58 nGy h<sup>-1</sup> (18–93 nGy h<sup>-1</sup>)<sup>(1)</sup>. The average of the absorbed gamma dose rates is statistically indistinguishable from the quoted average value. The corresponding AED was estimated taking into account the absorbed gamma dose rates. The estimated values of the corresponding AED are given in the third column of Table 2. The values of the AED varied from 6.3 to 150.0 μSv y<sup>-1</sup> with a mean of 66.5 ± 5.9 μSv y<sup>-1</sup>.

The calculated values of  $H_{\text{ex}}$  for the soil samples are given in the last column of Table 2. It can be seen from that all the values of  $H_{\text{ex}}$  are lower than unity. The soil in this studied field is safe recalling that it is closed to settlements.

## CONCLUSIONS

The activity concentrations of <sup>238</sup>U, <sup>232</sup>Th, <sup>40</sup>K and <sup>137</sup>Cs in 30 soil samples collected from the Kızılırmak

Delta were determined. The results show that the mean value of activity concentration of <sup>238</sup>U is statistically the same as the world average. After nuclear weapon tests and some nuclear accidents <sup>137</sup>Cs and <sup>134</sup>Cs can be released into the environment. These radionuclides can be transferred by some meteorological events such as wind to thousand of kilometres. The authors think that the <sup>137</sup>Cs activity concentration was due to Chernobyl accident and around 500 atmospheric nuclear weapon tests conducted until 1980. Fukushima nuclear accident which happened in March 2011 has no effect on the activity concentration of <sup>137</sup>Cs measured in the samples because the soil samples were collected before January 2011. The absorbed gamma dose rate and AED values have been estimated and the mean values of these quantities are statistically indistinguishable from the world average values.  $H_{\text{ex}}$  is less than unity which means that there is no radiation hazard in this area.

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