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ORIGINAL ARTICLE

Radioactivity in sediments and gross alpha–beta activities in surface water of Fırtına River, Turkey

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Abstract The concentrations and distribution of natural and artificial radionuclides in sediment and water samples collected from Fırtına River in the Eastern Black Sea region of Turkey were investigated with an aim of evaluating the environmental radioactivity and radiation hazard. Natural gross α and gross β activities were determined for 21 different water samples, and the activity concentrations were obtained for ^{226}Ra, ^{214}Pb, ^{214}Bi, ^{228}Ac, ^{208}Tl, ^{40}K and ^{137}Cs in 20 different sediment samples. The obtained results showed that natural gross α and gross β activity concentrations in water samples range from 12.4 ± 3.4 to 66.2 ± 9.2 mBq l^{-1} and from 27.9 ± 3.3 to 133.3 ± 4.1 mBq l^{-1}, respectively. The mean activity concentrations were 32.6 ± 3.8 mBq l^{-1} for gross α and 69.9 ± 4.4 mBq l^{-1} for gross β. Generally, the gross β activities were higher than the corresponding gross α activities. The average concentrations of ^{238}U and ^{232}Th daughter products vary from 11 to 167 Bq kg^{-1} and from 16 to 107 Bq kg^{-1}, respectively. The concentrations of ^{40}K and ^{137}Cs vary from 51 to 1,605 Bq kg^{-1} and from 0.8 to 42 Bq kg^{-1}, respectively. Sediment characterization was also investigated using grain size, thin section and XRD analysis.

Keywords Fırtına Valley, Sediment · Water · Natural and artificial radioactivity · Gross α and β

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Introduction

The Fırtına Valley is one of the main natural water sources in the North-East of Turkey. It reaches to 2,400 m altitudes abruptly and has an untouched ecosystem with lots of rare species. Situated in the Caucasus Ecoregion, the Fırtına Valley is one of the few areas with the best samples of warm-temperate deciduous forests existing without interruption since the Tertiary. The average annual rainfall rate in the valley is about 2,000 mm, and higher parts of it are generally under heavy fog. Since it habituates jungles, borealis, conifers, mixed forests, alpines, rocky habitats and all kinds of living organisms which can only be found in the North-East of Turkey, the valley is among one of the one hundred valleys in the world which have been announced by the WWF as preserved regions. Nearby Kaçkar Mountains National Park can be enlarged with corridors to include Fırtına Valley for better conservation of the area. WWF-Turkey has recently realized a project "Raising Public Awareness and Education for Efficient Protection of Kaçkar Mountains National Park and Fırtına River" with a local NGO, Black Sea Environmental Society (WWF 2005).

The exposure of human beings to ionizing radiation from natural sources is a continuing and inescapable feature of life on earth. For most individuals, this exposure exceeds that from all man-made source combined. 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 ore present everywhere in the environment. Both external and internal exposures to humans arise from these sources (UNSCEAR 1993).

The radionuclides ^{40}K and ^{238}U, ^{232}Th and their daughter's radionuclides make the biggest contribution to the total background dose. Radium radionuclides are of radiological importance to human; water and aquatic lives and plants contain radium radionuclides taken up from river soil and sediment. Rivers transport particulate materials and dissolved species from land to sea. Qualitative and quantitative knowledge of the natural radioactivity in river and coastal ecosystems is important in itself because it concerns the most abundant radionuclide (^{40}K) and other radionuclides liable to cause radiation protection problems under extreme conditions (Chowdhury et al. 1999).

Water quality is an important parameter of environmental studies. Radioactivity present in surface waters is mainly due to the presence of radioactive elements on the earth's crust. Recently, other artificial radionuclides have appeared due to such human activities as nuclear power plants, nuclear weapons testing, and manufacture and use of radioactive sources. In addition, human activities such as mining, milling and processing of uranium ores and mineral sands, manufacture of fertilizers, burning of fossil fuels have raised naturally occurring radioactive material concentrations in the environment (Pujol and Sanchej-Cabeza 2000). Radioactive material can reach surface waters in different ways from each of the process or activities that produce technologically enhanced radioactive material. River water can be contaminated by surface runoff of rainwater transporting leached radionuclides from cities, mine waste, agricultural areas, and so on (O'Brien et al. 1998).

Natural waters contain both α and β emitters in widely varying concentrations which are responsible for a generally small fraction of the total dose received from natural and artificial radioactivity (UNSCEAR 1993). For practical purposes, the recommended guideline activity concentrations are 0.5 Bq l^{-1} for gross α and 1 Bq l^{-1} for gross β activity (WHO 2004). The recommendations do not show any difference between naturally occurring and artificial or man-made radionuclides.

The main motivation for this study is due to the fact that the Fırtına River washes up various geological structures to the Black Sea, and this region contains more radioactive granite type rocks than other regions. To our knowledge there is no work on this special geographical area in terms of α and β activities. Furthermore, the Black Sea region being nearer to the reactor accepted great quantity of direct atmospheric radionuclide fallout.

The present work is a continuation of our earlier work (Kurnaz et al. 2007), and the aim is to determine the level of gross α and gross β activity in surface waters of Fırtına Valley in the Eastern Black Sea Region of Turkey. In addition, to control and monitor radioactivity levels in Fırtına Valley, the concentrations of natural (^{238}U, ^{232}Th, ^{40}K) and artificial (^{137}Cs) radionuclides were measured in sediments collected at different localities. The accumulation of information on natural radiation is a great value for radiation protection. The sediments can be regarded as a mildly dynamic system, with a large number of parameters affecting the distribution of the radionuclides, conditioning their mobility in this compartment itself and in its interfaces with other compartments, mainly water and suspended materials (Lozano et al. 2002). The results of this study will provide background data on the natural and artificial radioactive isotopes and environmental pollution.

Experimental methods

Geology of the study area

The Fırtına River originates at slopes of the Kaçkar Mountains and discharges to the Black Sea at 2 km near Ardeşen in the east of Rize in the Eastern Black Sea Region of Turkey. The Fırtına River is 60 km long. The Fırtına Valley stands between 41°07′–40°59′ north latitudes and 40°50′–40°57′ east longitudes. Along the river course, there are no large cities, non-nuclear enterprises such as chemical and phosphate industries and coal-fired power plants. Farmers live in this region and they generally raise tea and some vegetables. Therefore, some fertilizers contaminate the Fırtına River. Geology of the studied area is given in detail by Boztuğ et al. (2006). So, the summary of geological background was only given here. Eight lithological units including the Kaçkar batholith were observed in the studied area. The oldest unit is the Hamurkesen Formation of Liassic age (MTA 1998). It is unconformably overlain by the widespread arc-volcanic rocks, represented, from bottom to top, the Çatak, Kızılkaya and Çaglayan volcano-sedimentary formations of Maastrichtian age. These units consist essentially of submarine volcanic eruptions associated with epiclastic and calcereous sediments (Boztuğ et al. 2006). They unconformably overlie the Eocene aged Kabaköy Formation, comprising alkaline basalts and pyroclastics (MTA 1998). Boztuğ et al. (2006) stated that Kaçkar batholith is a composite one and was formed by five different magmatic episodes. According to Boztuğ et al. (2006), Paleocene aged Asniyor leucogranite was formed during the third intrusive pulse. More about the formation of the composite Kaçkar granitoid can be found in Boztuğ et al. (2006). A few meters thick alluvium along the Fırtına River Valley and Black sea coasts are recent deposits.

Measurements of gross α and β Activities

In order to measure the gross α and β activities in Fırtına River waters, samples were collected from 21 different sites of Fırtına Valley. Water samples were collected at a certain distance from the river bed (at every 3 km) and sufficiently far from the riverbank. Surface water samples were collected in 1.5 l linear polypropylene bottles which had been carefully washed in the laboratory before the sampling. The collected water samples were acidified with concentrated nitric acid to pH 1 to avoid the collection of organic materials and changes in the state of the ions present in the samples. Subsequently, samples were slowly evaporated in a furnace at 60°C down to a 50 ml volume. The residue was transferred quantitatively to a stainless-steel planchet and dried. The sample was allowed to equilibrate with ambient temperature and then weighed. The counting time was 50,000 s for gross α and β activities.

Measurements of radioactivity level in all water samples were performed by Krieger's method using the gross α and gross β counting system (Krieger 1975). The device, used to count the gross α and β activities, was a α/β counter of the low background multiple detector type (Berthold LB770). The sample detectors are gas flow window-type counters which are approximately 5 cm in diameter. The counting gas was a mixture of 90% argon and 10% methane. All samples were placed in a 5 cm diameter stainless-steel planchet for counting. Lead shielding was used to attenuate external radiation. The operating voltage on the detector was selected to be 1,650 V.

The system was calibrated for α and β energies by preparing standard samples which contain equal concentrations. ^{241}Am (913 Bq) and ^{90}Sr (931 Bq) were used to calibrate the system for α and β energies, respectively. The counting efficiencies for the system are 19–21% for α and 71–73% for β.

Background and efficiency data for the detector were collected, stored and used for corrections. The background of the detector was determined with measurements for the length of time that routine samples were counted and were measured using a clean, empty planchet in detector. The repetitive determination of backgrounds served as a check on the operation of the system, with average values of 0.0015 and 0.02 cpm background counting rate for α and β, respectively.

The minimum detectable activity (MDA) is expressed as (Curie 1968):

$$\mathrm{MDA(Bq/l)} = \frac{\mathrm{L_d}}{VT\varepsilon 60} \quad (1)$$

with

$$\mathrm{L_d} = 2.71 + 4.65\sqrt{C_B T} \quad (2)$$

where V is the volume of sample (l), T (min) the sample measurement time (which is the same as for the background), ε the efficiency and C_B is the background count rate (counts per minute) using a radiochemical blank. Typical minimum detectable activities (MDA) for a counting time of 50,000 s were estimated to be 3 mBq l^{-1} for α and 6 mBq l^{-1} for β.

Measurements by Gamma Spectrometry

The sediment samples (at 0–15 cm depth level) were collected at 1 km intervals along the Fırtına Valley in the Eastern Black Sea region of Turkey. Figure 1 shows the location of sampling sites and the geological map of Fırtına Valley. Stone, grass and pieces of woods were manually eliminated and the rest of the sediment samples were filled into plastic bags (1–1.5 kg) until analysis. The detailed description of the sample preparation and measurement techniques are given in Kurnaz et al. (2007). Sediment characterization was also investigated using grain size, thin section and XRD analysis.

Results and discussion

Gross α and β activities

Gross α and gross β activity concentrations in water samples of Fırtına Valley are given in Table 1. The gross β activity is generally higher than the corresponding gross α activity (Table 1). Total α and β activity concentrations for all water samples are found to be lower than 0.5 and 1 Bq l^{-1}, respectively. These levels are recommended by WHO. Water from this river is used by the people of Ardeşen, which is a small town in the discharging area, and bysurrounding villages as drinkable water. Hence, all water samples taken from the Fırtına Valley are suitable for drinking.

The gross α activities range between a minimum of 12.4 ± 3.4 mBq l^{-1} and a maximum of 66.2 ± 4.6 mBq l^{-1}. The gross β activities range between 27.9 ± 3.3 and 133.3 ± 4.1 mBq l^{-1}. Mean gross α and β activities in Fırtına river waters were 32.6 ± 3.8 and 69.9 ± 4.4 mBq l^{-1}, respectively. It is estimated that almost 100% of gross α and 97% of gross β activities of surface waters in the Fırtına River come from natural sources. As a rule, the origin of the gross α and gross β activities was not investigated. The main natural radionuclide contributions to gross activities in waters are uranium and radium and its α daughter for gross α activity and ^{40}K and ^{226}Ra β daughters for gross β activity (Osmond and Cawart 1992).

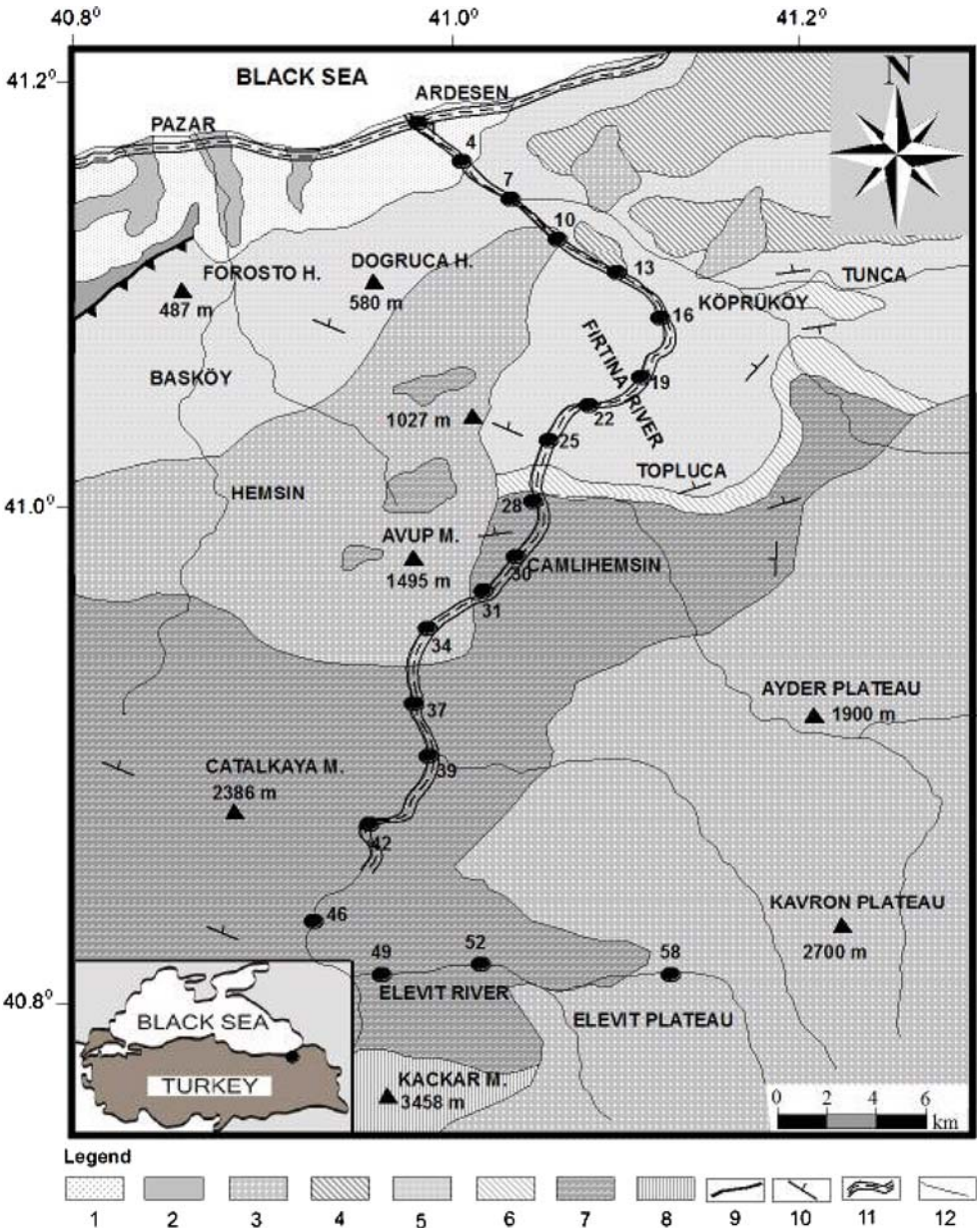

Fig. 1 The location of sampling sites and geological map of Fırtına Valley (*1* quaternary alluvium, *2* Eocene aged Kabakoy Formation, *3* Upper Crateceous-Eocene Kackar Granitoid, *4* Upper Cretaceous aged Cayırbag Formation, *5* Upper Cretaceous aged Caglayan Formation, *6* Turonian-Coniacian aged Kızılkaya Formation, *7* Upper Cretaceous aged Catak Formation, *8* Liassic aged Hamurkesen Formation, *9* fault, *10* strike and dip, *11* road, *12* river)

An enhancement of gross α activity was observed in some region, especially from the 48th to the 54th kilometer, of Fırtına River. This can be explained by the radioactive material from granite rocks in these regions (Fig. 1). Similarly, gross beta activity also increased in some regions of Fırtına valley. Potassium contents of waters caused by the intensive use of fertilizers in the agricultural areas increase β activity.

The uncertainties in the present measurements are approximately 3% for gross α and 5% for gross β. These uncertainties are the sum of the errors caused by the preparation of standards for α and β sources, and the emission rates occurring on the α and β standards as a result of the applied method used for source preparation (Damla et al. 2006).

Radioactivity analysis of the sediment samples

The natural radioactivity of sediment depends on the characteristics of the source rocks and secondary processes that were involved since sediment formation. Chemical and biochemical interactions influence the contribution patterns of uranium, thorium and their decay products (Malanca et al. 1998).

The activity concentrations of ^{232}Th and ^{238}U were calculated assuming secular equilibrium with their decay products. For concentrations of ^{232}Th and ^{238}U, the following gamma transition lines were used. ^{232}Th: 583.1 keV (^{208}Tl) and 911 keV (^{228}Ac), ^{238}U: 186 keV (^{226}Ra), 351.9 keV (^{214}Pb), and 609.2 keV (^{214}Bi). The

Table 1 Activity concentrations for gross α and gross β in Fırtına River waters

Distance from sea (km)	Gross α (mBq/l)	Gross β (mBq/l)
1	18.6 ± 3.1	72.3 ± 4.1
3	14.6 ± 2.7	47.3 ± 3.3
6	12.5 ± 2.4	104.7 ± 4.4
9	14.6 ± 2.3	27.9 ± 3.3
12	61.0 ± 3.3	52.6 ± 3.7
15	22.5 ± 2.9	133.3 ± 4.1
18	42.1 ± 6.9	57.9 ± 7.0
21	49.7 ± 7.9	87.9 ± 7.3
24	31.2 ± 3.0	66.9 ± 4.4
27	25.0 ± 2.8	118.8 ± 4.4
30	12.4 ± 3.4	51.4 ± 3.7
33	26.8 ± 2.7	40.0 ± 3.4
36	21.0 ± 3.0	57.8 ± 3.4
39	21.9 ± 3.7	45.4 ± 4.5
42	24.2 ± 3.7	38.9 ± 4.0
45	34.0 ± 3.7	52.9 ± 4.3
48	64.6 ± 3.2	60.9 ± 4.2
51	66.2 ± 4.6	84.5 ± 8.0
54	65.4 ± 9.2	123.1 ± 4.4
57	37.6 ± 3.4	78.1 ± 3.6
60	19.8 ± 2.9	65.9 ± 3.4

activity concentration of ^{40}K was determined from the peak areas at 1,460 keV. The 661.6 keV gamma transition was used to determine the ^{137}Cs concentration.

Table 2 shows the dry weight activity concentrations of the main gamma emitting radionuclides of the ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in the sediment samples. The average concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs were found to be 39.93, 38.55, 573.34 and 6.15 Bq kg^{-1} (dry weight) in sediment samples, respectively.

The activity of ^{238}U and ^{232}Th in Fırtına River sediments are nearly equal. The world average of ^{238}U and ^{232}Th activity is 25 Bq kg^{-1} and ^{232}Th/^{238}U quotient is 1.0 (Chowdhury et al. 1999). The activity of ^{238}U and ^{232}Th in this study are higher than the world average. In addition, Fig. 2 shows distribution of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs activity concentrations of sediment samples in Fırtına Valley.

The distribution of these radionuclides in the samples is not uniform. The activity ratios of radionuclides are presented in Table 3. The mean ^{226}Ra/^{238}U ratios in the Fırtına River sediments indicate the status of the radioactive secular equilibrium between ^{226}Ra and ^{238}U. The ^{238}U/^{40}K ratio range from 0.033 to 0.7 and average value was found to be 0.137 and the ^{232}Th/^{40}K ratio range from 0.037 to 0.615 and average value was found to be 0.150, the world average for both quotients being 0.067 (UNSCEAR 1988).

Table 2 Radioactivity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in Bq/kg, as well as the calculated gamma activity concentration index (I_γ) in sediment samples at Fırtına Valley

Distance from sea (km)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	^{137}Cs (Bq/kg)	I_γ
1	23.28	22.33	599.11	7.06	0.39
4	39.79	38.98	563.32	6.59	0.52
7	30.36	30.02	426.12	5.37	0.39
10	25.46	26.07	661.03	7.35	0.44
13	21.28	21.65	462.35	3.29	0.33
16	30.32	28.36	270.69	2.26	0.33
19	27.10	25.75	538.08	5.71	0.39
22	29.01	29.15	398.99	41.72	0.37
25	20.98	21.51	337.75	1.92	0.29
28	16.93	17.26	355.35	3,00	0.26
30	16.1	20.49	478.66	4.00	0.32
31	17.03	40.48	92.46	1.57	0.29
34	25.74	31.65	51.41	0.87	0.26
37	45.00	55.92	105.73	1.80	0.46
39	51.62	35.72	544.87	3.41	0.53
42	65.06	56	1472.10	5.10	0.99
46	61.40	51.29	1152.93	5.90	0.85
49	56.96	60.30	1189.19	4.06	0.89
52	82.05	70.61	1605.26	9.23	1.16
58	113.25	87.45	161.34	2.74	0.87

^{137}Cs does not exist in sediment naturally. It is a product of fallout radioactivity. The ^{137}Cs might have been deposited in sediments of Fırtına Valley, presumably as a result of the nuclear power plant accident at Chernobyl on 26 April 1986. Significant differences in ^{137}Cs activity in sediment samples were observed. ^{137}Cs activities in the sediment samples vary from 0.87 to 41.72 Bq kg^{-1} and average of 6.15 Bq kg^{-1} were observed. In general the ^{137}Cs activity levels of sediment samples are low. This can be attributed to the effect of water on the sediment.

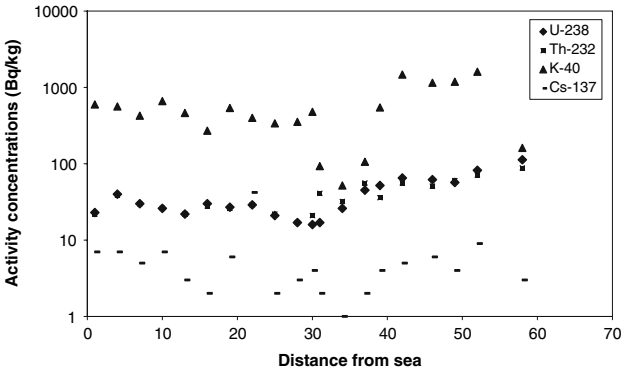

Fig. 2 Variation of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs concentrations in sediment samples

Table 3 Activity of radionuclides in sediment samples and their activity ratios

Nuclide and activity ratio	Min	Max	Average
^{226}Ra (Bq/kg)	15.20	116.55	47.41
^{238}U (Bq/kg)	16.10	113.25	39.93
^{232}Th (Bq/kg)	17.26	87.45	38.55
^{40}K (Bq/kg)	51.41	1605.26	41.72
^{137}Cs (Bq/kg)	0.87	41.72	6.15
^{226}Ra/^{238}U	0.94	1.40	1.17
^{232}Th/^{226}Ra	0.59	1.98	0.91
^{232}Th/^{238}U	0.69	2.37	1.05
^{226}Ra/^{40}K	0.032	1.032	0.173
^{238}U/^{40}K	0.033	0.70	0.137
^{232}Th/^{40}K	0.037	0.615	0.150

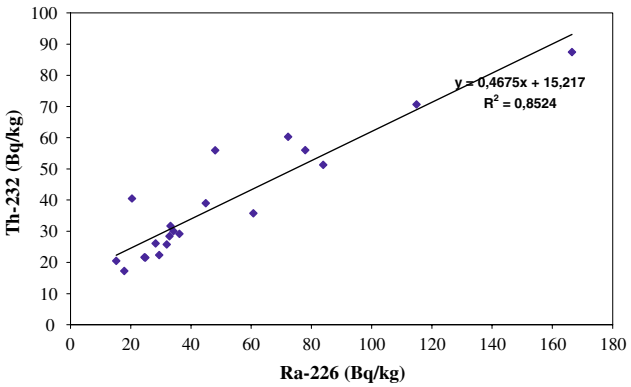

Fig. 3 Scatter plot of sediment radium versus sediment thorium with *linear regression line*

Gamma activity concentration index (I_γ) is derived (Ahmad et al. 2006):

$$I_\gamma = A_U/300 + A_{Th}/200 + A_K/3000 \quad (3)$$

where A_U, A_{Th} and A_K are the U, Th and K specific activity concentrations (Bq kg^{-1}), respectively, and the factors

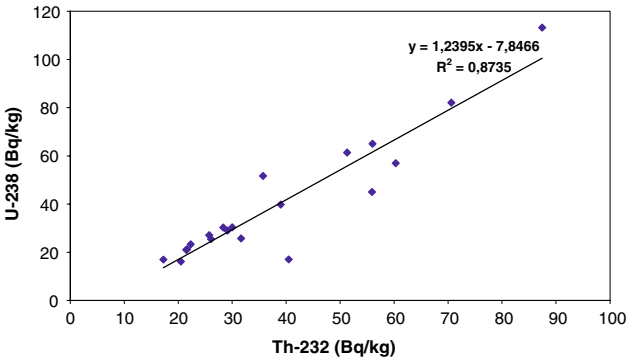

Fig. 4 Correlation between activity concentrations of ^{238}U versus ^{232}Th

Table 4 Sample characteristics and the results of the grain size analysis

Sample no.	Sand	Silt	Clay	Texture
1	18.50	36.35	45.15	Mud
4	25.95	33.84	40.21	Sandy mud
7	29.28	27.97	42.75	Sandy mud
10	23.04	37.46	39.50	Sandy mud
13	18.04	44.76	37.20	Mud
16	23.64	43.85	32.51	Sandy mud
19	36.07	23.89	40.04	Sandy mud
22	22.32	36.90	40.78	Sandy mud
25	12.11	45.58	42.31	Mud
28	24.29	40.23	35.48	Sandy mud
30	11.91	40.39	47.73	Mud
31	16.29	44.14	39.57	Mud
34	3.92	51.52	44.56	Mud
37	22.05	40.59	37.36	Sandy mud
39	21.87	28.67	49.46	Sandy mud
42	15.39	25.10	59.54	Mud
46	27.21	26.19	46.60	Sandy mud
49	12.35	31.56	56.09	Mud
52	29.47	33.25	37.28	Sandy mud
58	15.29	46.53	38.18	Mud

300, 200, 3000 Bq kg^{-1} were calculated for a dose criterion limit of 1 mSv year^{-1}. This index can be used to estimate the level of γ radiation hazard associated with the natural radionuclides. The gamma activity concentration index (I_γ) was calculated, and the values are given in Table 2. The values in sediment samples vary from 0.26 to 1.16 and average value was found to be 0.52. The world average for I_γ value being 0.66 Bq kg^{-1} (UNSCEAR 1988).

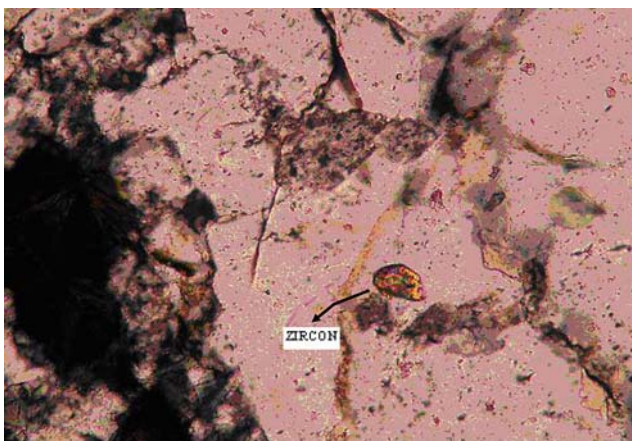

Fig. 5 A zircon mineral in the granite sample collected from studying area

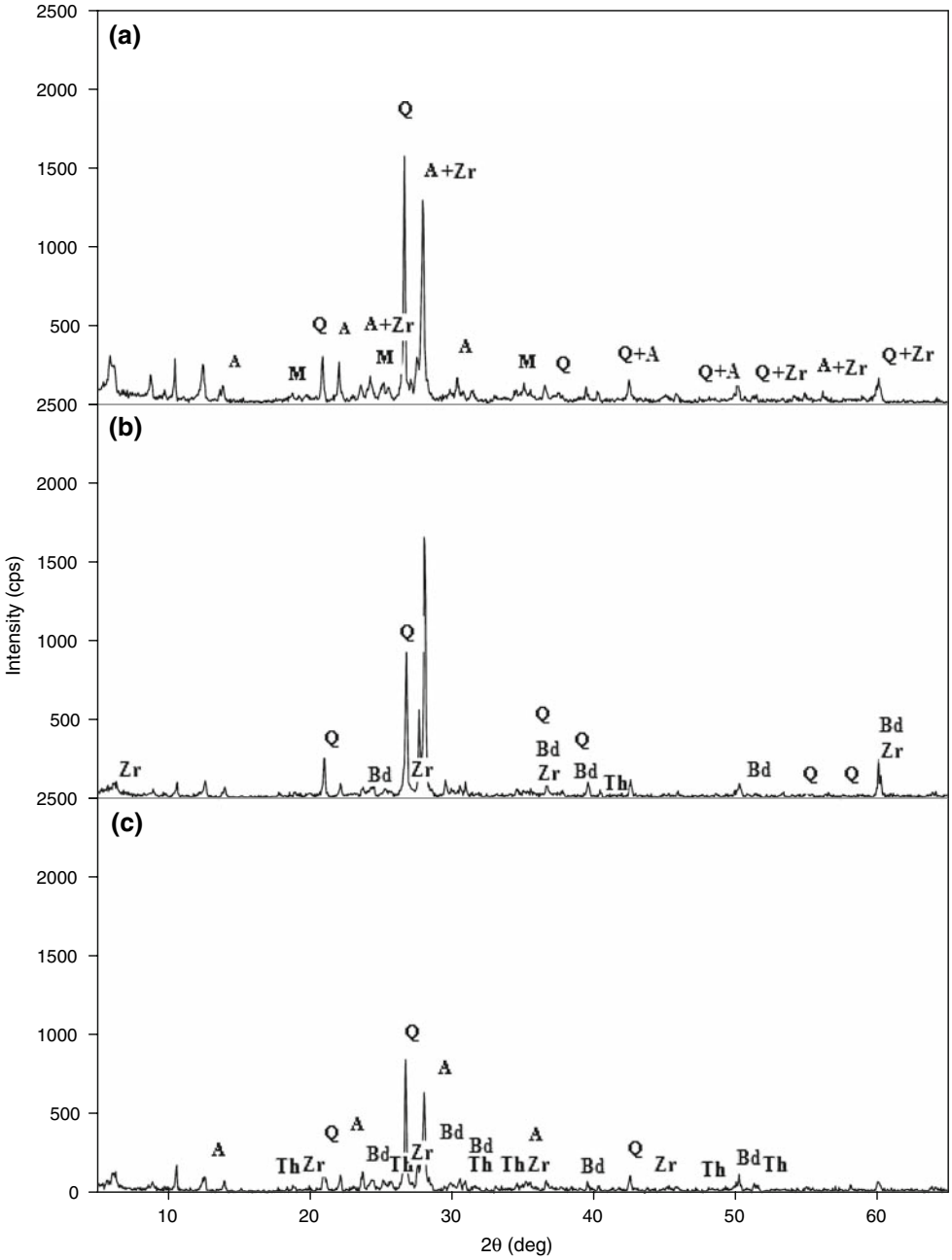

Fig. 6 XRD analysis of the sample 34: **a** soil, **b** silt, **c** clay (*Q* quartz, *A* albite, *M* muscovite, *Zr* zircon, *Th* thorite, *Bd* baddeleyite)

Correlations

The correlation between the activities of ^{226}Ra, ^{232}Th and ^{238}U for sediment samples are shown in Figs. 3 and 4. As shown in Figures, the correlation between ^{226}Ra and ^{232}Th in sediments of Fırtına Valley is high with a correlation coefficient 0.85. Such a correlation indicates that the correlation of ^{226}Ra and ^{232}Th are representative of a common geological origin. The concentrations of ^{238}U and ^{232}Th are significantly correlated ($R^2 = 0.87$). The lines represent values calculated by linear fit.

Grain size analysis

After all sediment samples were dried at room temperature, samples were fractioned by dry sieving. Textural characterization and grain size of samples were carried out. According to Whitlow (1983), grains with diameter ranging from 63 to 2000 μm, from 16 to 63 μm and less than 16 μm comprise the sand, silt and clay fractions, respectively. Sediment is defined as: (1) sand or muddy sand when the sand fraction is above 50%; (2) mud, if it contains more than 80% fine-grained material (silt and clay

Table 5 Mean concentration of gross alpha and beta radioactivity in waters from a number of rivers in the world

River	Gross α (mBq/l)	Gross β (mBq/l)
Severn (Hesketh 1982)	220	410
Ebro (Pujol and Sanchez-Cabeza 2000)	95	213
Kankakee (Sidle et al. 2001)	78	168
Sao Rafael (Malanca et al. 1998)	20	197
Fırtına (Rize, Turkey)	33	70

fraction); and (3) sandy mud, if the sum of the silt and clay fraction varies between 50 and 80% (Whitlow 1983). Table 4 shows the results of the grain size analysis.

Thin section analysis

The thin section analysis of the granite samples, collected from the study area, shows that they are granodiorite and the following minerals were observed. The Asniyor leucogranite has equigranular to porphyritic textures consisting of quartz, orthoclase, plagioclase and chloritized biotite (which are scarce in the modal mineralogical composition). All these minerals include some zircon grains. There is widespread hydrothermal alteration in the Asniyor leucogranite which resulted in alteration of feldspars to kaolinite and secirite. Although most of the samples are granite in composition, some of them are tonalite. Figure 5 shows the thin section analysis of the granite sample.

XRD analysis

The XRD analysis was carried out on one of the sediment sample (34). Figure 6a–c shows XRD analysis of the sand, silt and clay fractions in the sample 34. Although there is not much Zr in the sample, some of the zircon peaks were observed under the background, and some of them overlap with albite and quartz peaks. Thorite and baddeleyite compounds and zircon element were observed with fewer amounts in the clay and the silt fractions of the sample. Also, the thin section investigation of the granite samples supports the presence of zircons in the sample (Fig. 5).

Conclusion

The aim of this study was to provide background information for the Fırtına Valley which is one of the first 100 regions that have been determined to be especially

Table 6 Average radioelement content in rocks (Lima et al. 2005)

	K (%)	U (mg/kg)	Th (mg/kg)
Granite	3.2	4.8	17
Andesite	–	2	–
Basalt	0.8	0.6	2.2
Limestone	0.3	2	2
Shale	2.7	4	12

preserved by the WWF (2005). The results obtained show that the levels of gross α and β in the Fırtına River are lower than the rivers in the world (Table 5).

The obtained data cover a wide area in Fırtına Valley originated at the slopes of Kaçkar Mountain and discharged to the Eastern Black Sea. The mean concentrations of the radionuclides ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in sediment samples determined in this study compare suitably with literature values. The results indicate that ^{40}K is the only radionuclide present in a significant amount in sediment samples, whereas the other radionuclides are only present in nominal concentrations. From measured values, gamma activity concentration index (I_γ) was found.

Natural radioactivity has geogenic sources derived primarily from naturally occurring U, Th, and K, which are present in rock forming minerals. Radioactivity in the surface waters of Fırtına River was natural. It is assumed that the gross α activity derived mainly from uranium and radium and its alpha daughters, and that the gross β was mostly due to ^{40}K, ^{226}Ra beta daughters and ^{90}Sr. The enhancement of gross α activity in some parts of the river waters is mainly due to the increase in uranium concentration and ^{226}Ra and its daughters, since the level of uranium concentration for granite type rocks is generally known to be higher than other kinds of rocks (Table 6) (Lima et al. 2005).

In view of the large proportion of volcanic and plutonic rocks along the course of the river, the dominant ^{40}K gamma ray activity might be due to a considerable amount of feldspar and derived clay minerals in river sediments. Also, the enhancement of gross β activity in the Fırtına Rivers may be due to the increase in potassium concentration. Agricultural fertilizer products contain various trace elements such as uranium and thorium decay series members and ^{40}K (NCRP 1987). The use of fertilizers in agricultural areas can increase the concentration of these natural radionuclides in the soil. Health effect due to natural radiation from water and sediment of the Fırtına Valley is low and thus health hazards are insignificant. It seems necessary to determine the radioactivity concentrations in water and sediments of other parts of Turkey. The present study provides a general background of the detectable radionuclides and will be helpful in any

radiological emergency. This study can be used as a baseline for future investigations.

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