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Assessment of natural radioactivity and heavy metals in water and soil around seismically active area

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Abstract The natural radioactivity concentration and some heavy metals in various water and soil samples collected from seismically active area have been determined. Gross-alpha and beta concentrations of different 33 water samples and some heavy metal (Fe, Pb, Cu, K, Mn, Cr and Zn) concentration in 72 soil samples collected from two major fault systems (North and East Anatolian Active Fault Systems) in Turkey have been studied. This survey regarding gross-alpha and beta radioactivity and some heavy metals concentrations was carried out by means of Krieger method using a gross-alpha and beta-counting system and atomic absorption spectrometry (AAS), respectively. Also, gross annual effective dose from the average gross-alpha activity in waters were calculated.

Keywords Gross alpha and beta · Fault systems · Heavy metals · Soil · Water

Introduction

The natural occurring radioactive materials (NORM) are always having been a part of our world since it exists [1]. The natural or artificial radioactive nuclides are main source of radiation exposure for human begins and constitute background radiation levels. Based on some specific characteristic (e.g., geological one) of the region the concentrations of the gross-alpha and beta radioactivity of water vary from one region to another in the world. But, the amounts of radioactivity (especially radium and radon) in fault regions and/or fracture zones tend to be higher than others regions. One of the reasons of increase in radioactivity concentration over the fracture zones is dissolving of uranium ions and/or daughter nuclides the in ground water. However, they have been precipitated close to the ground surface soil or fracture/fissures. Fracture zones are usually easy way for uranium movements, transitions and depositions [2].

Since rock and soil contain uranium, both ground and surface waters should contain the alpha emitter radionuclides. Therefore, uranium content soil which surrounding water source is highly affects the radon and radium concentration in water. Hence, the natural radioactivity of gross alpha and beta in both ground and surface waters could be expected to be relatively higher than waters samples which collected out of fault zones [3, 4]. In the previous work on same area, it is found that the gross-alpha and beta radioactivity concentration and the radioactive analyses of the certain groundwater in main faults and some auxiliary active faults were found to be relatively higher [5, 6]. Especially, the high radon emanation in soil where the uranium concentration is high, along the fracture zones, contributes significantly to radon concentration in water [3].

Heavy metals are natural constituents of the Earth crust. The presences of heavy metals in soil are natural and anthropogenic. Main anthropogenic sources of heavy metals exist in various industrial sources and agricultural activities.

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End the results of these activities are constituted soil pollution by heavy metals. The maximum permissible levels of metal concentrations in soil were complied with the idea of preventing toxic exposure of plants, animals and humans [7]. Generally, the distribution of heavy metals is influenced by kind of main source, climate and relative mobility depending of soil parameters such as mineralogy, texture and category of soil, pH and Eh [8]. The heavy metals can be retained by soil and mobilized to soil solution by biological and chemical mechanisms with a potential impact on human health such as contamination of drinking water supplies. However, there are many studies in literature concerning with determination of heavy metals in different environmental samples such as river sediments, herbal plants and soil etc. [9–11].

The aim of this work is to study the natural radioactivity (gross-alpha and beta radioactivity) of water and some natural heavy metal concentration (Fe, Pb, Cu, K, Mn, Cr and Zn) in soil (unaffected) and water collected from two major intersect fault systems (North and East Anatolian Faults System) in East of Turkey. Heavy metal concentrations and distribution are influenced by regional background levels. Especially, geological factors are major controls on the distribution of metals. Therefore, investigation of heavy metal concentration in unaffected soil of seismically area is very important. These kinds of results are not encountered in the literature. However, the presences of the any relationship between heavy metals and gross-alpha and beta radioactivity in soil and water samples of the same area have been studied. This survey regarding gross-alpha and beta radioactivity and some heavy metal concentrations was carried out by means of Krieger method using a gross-alpha and beta-counting system and atomic absorption spectrometry (AAS), respectively. This is the first study to assess the levels of background radiation and heavy metals of this seismically active area. Also, gross annual effective dose from the average gross-alpha activity in waters were calculated.

Study area

Water and soil samples were collected from the East and North Anatolian Faults System (EAFS) in Turkey as indicated in Fig. 1. EAFS is an about 30 km wide, 700 km long and N–E trending sinistral another mega shear zone between Anatolian platelet in the North and African-Arabian plates in the south. The rock units of the studied area are Paleozoic and Cenozoic formations. In the studied area Paleozoic formations is presented marble, schist and quartzite. The Cenozoic formations, which unconformably cover Paleozoic formation, consist of marble, limestone, basalts, andezite and travertine occurrences. The youngest

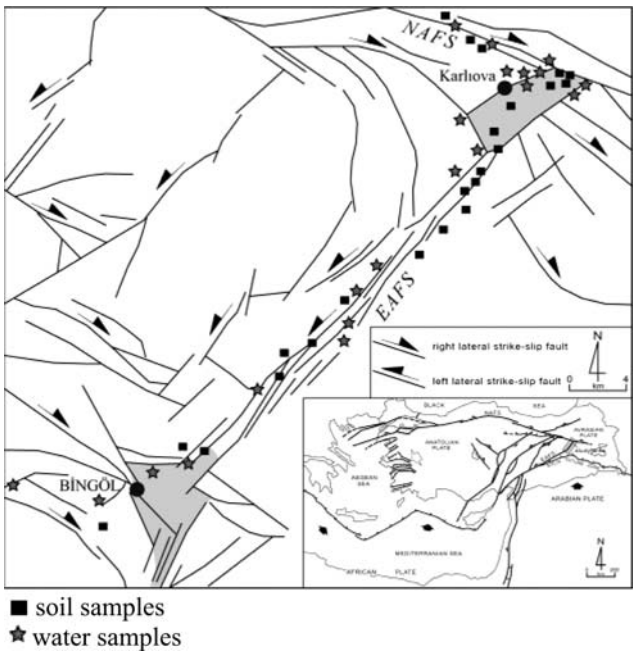

Fig. 1 **a** The map of Turkey. **b** The studied region

unit of the study area is Plio-Quaternary talus and riles deposits. EAFS are intercontinental transform fault, along which the wedge shaped Anatolian micro plate has been escaping west–south westward. The North Anatolian Fault System (NAFS) is one of the best-known strike-slip faults in the world because of its remarkable seismic activity, extremely well developed surface expression and importance for the tectonics of the eastern Mediterranean region. NAFS is an about 10–100 km wide, 1,200 km long and E–W trending dextral mega shear zone between Eurasian Plate in the north and the Anatolian Platelet in the south [12].

Materials and methods

Sample collection, preparation and measurement for radioactivity concentration in water and soil samples

33 water samples were collected into sterilized clean 2 L-polyethylene-bottles for subsequent preparation and analyses. 0.5 mL 3 N nitric acid was added to prevent the precipitation and absorption of the sample on the container walls. Each sample was divided into three equal parts. Each part was evaporated at low temperature (at about 60 °C) until a small amount of water remained. The residue was poured into about 4.6 cm^3 aluminum planchette and dried. The result was given as the arithmetic mean. The measurement of the radioactivity concentration of the water samples were performed by the Krieger method using a gross-alpha- and beta-counting system. The alpha radioactivity was counted by a ZnS(Ag) scintillator supported

by a photomultiplier tube with a 7286 low level alpha-counter from NE Technology, Inc. The ZnS(Ag) scintillator had a radius of 44 mm. Gross β-counting was performed by a low background plastic β-scintillation system supported by a plastic β-scintillator (2059) and a photomultiplier tube through a SR8 dual radiation counter from NE Technology Inc. Lead shielding were used for both systems for the protection against external radiation [13].

The gross-α and β were calculated using the net counts in the following equations;

$$A_\alpha = (N \times \mathrm{ECF})/0.016 \quad (1)$$

$$A_\beta = (0.0144 \times R \times N_\mathrm{m})/N_0 \quad (2)$$

where A_α and A_β are the α- and β-activities in Bq, respectively, N is the sample net counts per minute for alpha activity, ECF is the efficiency correction factor, R is the sample net counts for beta activity, N_m is the specific mass of the sample in mg/cm^2, N_0 is the count corresponding to the specific activity determined from the standard calibration curve obtained by a KCl source. The correlation coefficient (r) of the obtained curve was found to be 0.998. The correction factor ECF for alpha activity was obtained from the measurement of the sediment on the aluminum planchet;

$$\mathrm{ECF} = 1/E \times T \quad (3)$$

where T was determined from the U_3O_8 self-absorption curves, in mg/cm^2 and E is the absolute efficiency. The calculated standard deviation was found to be between 1 and 5% of the determined values.

A gross of 72 surface soil samples has been collected along the fault zones (EAFS and NAFS) at about 50 cm depth level (Fig. 1). 45 and 27 soil samples were collected from along East and North Anatolian Fault Systems, respectively. Due to the analyses of the heavy metal content of soil, the selected sampling points have not been taken close to the area where having an agriculture activity, near a road or other obstruction. After removing the stones, pebbles and organic materials, the samples were dried in an oven at about 85 °C for 3–5 h to remove the moisture content and then crushed pass to thought a fine mesh sieve ($\approx$100 μm) to homogenizes them.

Preparation and measurement for heavy metal analysis of soil

The soil samples were dried at 90 °C. Each 1 g of dried soils weighted accurately was dissolved in the mixture of nitric acid and hydrogen peroxide solution in a glass plate by heating. Each dried soil was added in 10 mL of 1.5 M HNO_3 solution and then diluted to 2 mL. The final extracts were transferred to test tube and centrifuged at about 5 min and then they were filtered (with 45 μm filters) into other test tube. Heavy metals were determined using ATI UNICAM 929 model atomic absorption spectrophotometry [8, 14]. AAS calibration was carried out using standard solutions whose concentrations ranged from 10 to 0.5 mg L^{-1}.

Results and discussion

The results of the gross-alpha and beta radioactivity concentrations of 33 water samples are shown in Table 1 with their standard deviation. The activity concentration of

Table 1 The gross-alpha and beta activity concentrations of different type water samples

Sample no.	Alpha activity (Bq/L)	Beta activity (Bq/L)	Type of water
1	0.081 ± 0.005	ND	Stream water
2	0.011 ± 0.004	0.084 ± 0.002	Stream water
3	0.007 ± 0.002	0.013 ± 0.001	Stream water
4	0.042 ± 0.001	ND	Spring water
5	0.008 ± 0.002	0.027 ± 0.001	Spring water
6	0.043 ± 0.003	ND	Spring water
7	0.018 ± 0.004	0.004 ± 0.001	Spring water
8	0.030 ± 0.006	0.013 ± 0.001	Spring water
9	0.022 ± 0.006	0.012 ± 0.001	Spring water
10	0.031 ± 0.003	0.032 ± 0.001	Spring water
11	0.167 ± 0.009	0.012 ± 0.001	Stream water
12	0.044 ± 0.002	0.043 ± 0.001	Spring water
13	0.008 ± 0.0019	0.053 ± 0.001	Stream water
14	0.082 ± 0.0029	0.011 ± 0.001	Spring water
15	0.049 ± 0.0039	0.023 ± 0.001	Spring water
16	0.014 ± 0.0026	0.026 ± 0.001	River water
17	ND	0.050 ± 0.002	Spring water
18	0.220 ± 0.035	0.012 ± 0.001	Stream water
19	0.146 ± 0.012	0.033 ± 0.002	Spring water
20	0.024 ± 0.006	0.044 ± 0.002	Stream water
21	0.171 ± 0.010	0.038 ± 0.001	Spring water
22	0.033 ± 0.005	0.090 ± 0.002	Spring water
23	0.077 ± 0.007	ND	Spring water
24	0.015 ± 0.004	0.035 ± 0.003	Spring water
25	0.278 ± 0.006	0.110 ± 0.004	Spring water
26	0.052 ± 0.006	ND	Spring water
27	0.332 ± 0.023	0.006 ± 0.001	Stream water
28	0.099 ± 0.014	0.026 ± 0.001	Spring water
29	0.076 ± 0.010	0.047 ± 0.001	Spring water
30	0.006 ± 0.002	0.092 ± 0.004	Spring water
31	ND	0.169 ± 0.004	Spring water
32	0.048 ± 0.006	0.039 ± 0.004	Stream water
33	1.689 ± 0.059	0.014 ± 0.004	Thermal water

ND not detected

gross-alpha and beta ranges from 0.006 ± 0.002 to 1.689 ± 0.059 and 0.004 ± 0.001 to 0.169 ± 0.004 Bq L^{-1}, respectively. In Table 1, the distributions of gross-alpha radioactivity concentration is higher and wider than the gross-beta radioactivity concentration (especially in spring and/or tap water samples). The important reason for this situation that the studied region has a lot of main and auxiliary active faults. However, it is possible that the soils in the area simply had high natural levels of radioactive materials, irrespective of seismicity. Some of auxiliary active faults have not been very well defined yet. The water sources that originating from bottom of the ground is transported to ground surface by means of main active faults and auxiliary faults. The higher alpha radioactivity concentration was found in thermal water (sample #33) collected from hotel situated at a hot spring. The higher beta radioactivity concentration was found in spring water (sample #31). It has also seen that, gross-alpha activity concentration of stream waters (the number of samples; 11, 18 and 27) which has direct contact to the soil in its flow pathway are also higher. So, the gross-alpha and beta radioactivity concentration of spring waters (using as drinking water) lower than recommendation for drinking water by World Health Organization (0.5 and 1 Bq L^{-1} for alpha and beta activity concentration, respectively) [15]. In order to estimate the gross annual effective dose from the average gross-alpha activity (based on ^{226}Ra), dose conversion coefficient of 2.8 × 10^{-4} Sv/Bq for ^{226}Ra (an alpha emitter) can be used assuming that an adult, on the average, consumes 2 L

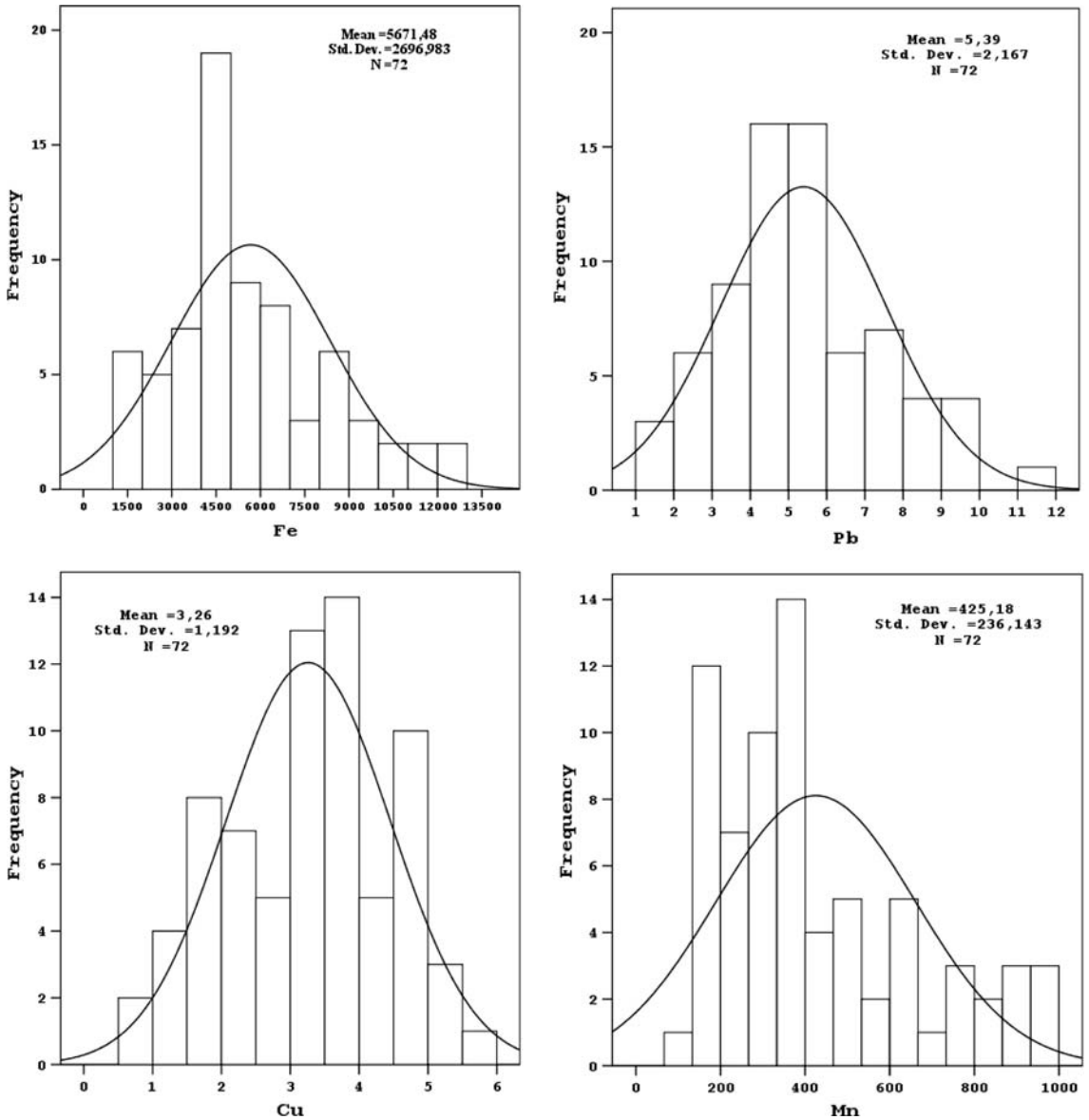

Fig. 2 The frequency distributions of heavy metal concentrations (mg/kg) of soil samples

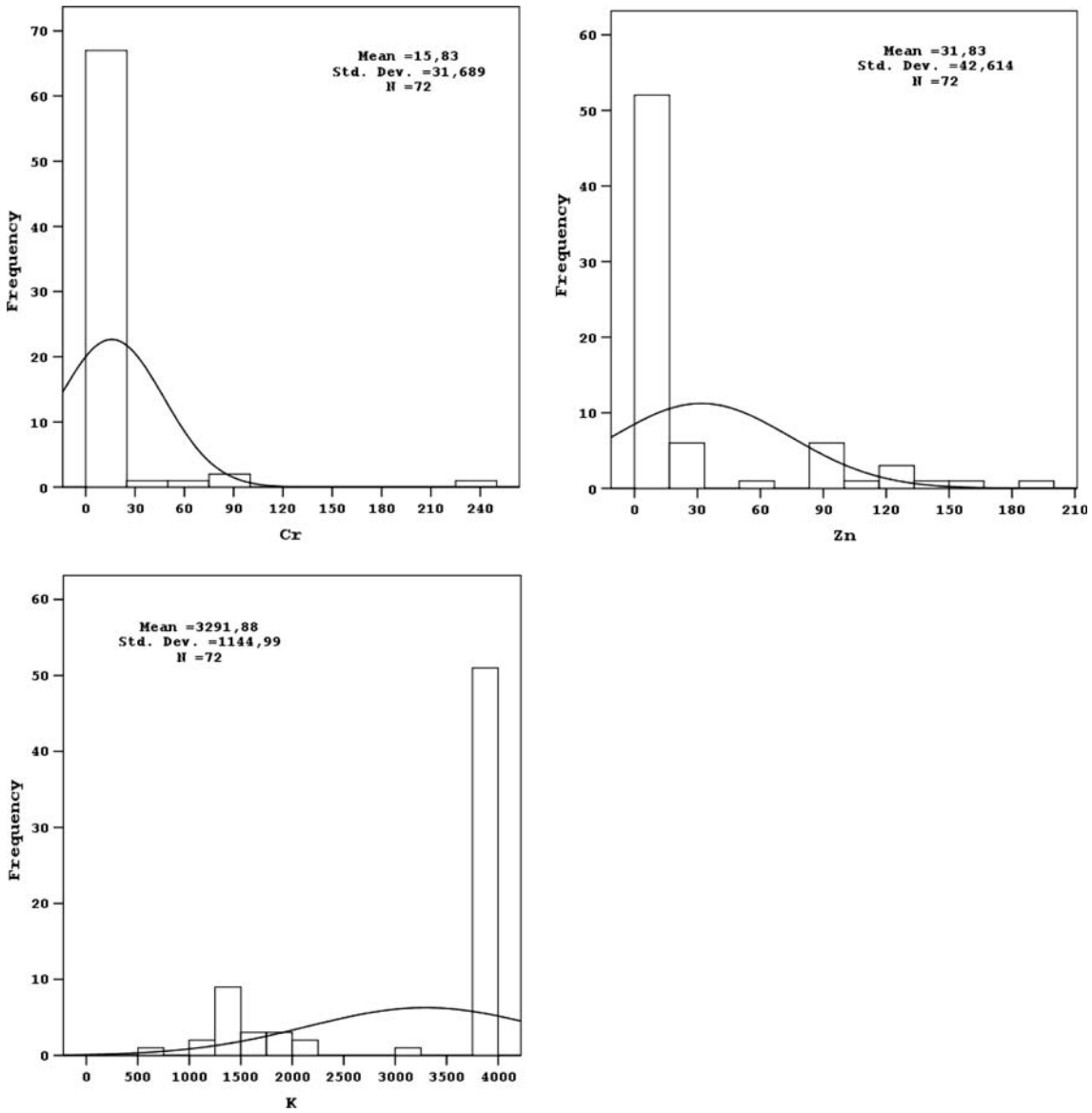

Fig. 2 continued

of water per day [15]. This leads to an annual effective dose of 61.6 μSv from drinking water (spring or tap water). This value is lower than the recommended annual effective dose for public of 1 mSv [16].

The frequency distributions of heavy metals in soil are shown Fig. 2. According to Fig. 2, the concentration of Fe for nineteen samples was about 5,000 mg kg^{-1}. In the six samples, Fe concentrations exceed about 10,000 mg kg^{-1}. The mean of Pb concentration was obtained as 5.29 mg kg^{-1}. Pb concentration of only one samples exceed 10 mg kg^{-1}. The concentration of Cu was about 4 mg kg^{-1} in thirteen samples while the value of Cu is high of 5 mg kg^{-1} in four samples. The range distribution of Mn concentrations were 100–968 mg kg^{-1}. The mean concentration of Cr and Zn was 15.83 mg kg^{-1} and 31.03 mg kg^{-1}, respectively. In the six samples, the concentration of Zn excess 100 mg kg^{-1}. The mean concentration of K is obtained as 3,291.08 mg kg^{-1}.

For comparison, our both results and the reported values for measured heavy metals in soil from some other countries are given in Table 2. As it is seen from Table 2 that the concentration of Pb and Cu are low compared to other studies. These results show that the obtained values, except for iron and potassium, are not high compared to some published data (Table 2). Especially, because iron is abundant in the soil, there is no limit to the iron concentration. But, these concentrations are natural heavy metal contents of soil because any anthropogenic activities such

Table 2 Concentrations values of some heavy metals, compared with the present study

References	Element													
	Pb (mg kg^{-1})		Cu (mg kg^{-1})		Mn (mg kg^{-1})		Cr (mg kg^{-1})		Zn (mg kg^{-1})		K (g kg^{-1})		Fe (g kg^{-1})	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range
[11]	–	51–180	–	23–101	–	–	–	41–97	–	41–219	–	–	–	–
[17]	38	19.5–86.3	30.9	12.3–85	678	398–939	68.6	48.3–89.7	109	53.9–271	12	1–20	94	30–341
[18]		10–84		6–80		80–1,300		7–221		17–125				
[19]	19.6	10–26	14.46	6–36	20.92	14–32	34.38	20–140	70.72	50–100			0.50	0.35–0.8
[20]		2–13.4		5–5.6		100–400		10–80		60–780				
Present work	5.39	1.05–11.64	3.25	0.55–5.73	425.18	100–980	15.82	1.48–247.26	31.82	6.34–187.85	3.29	0.62–4.00	5.67	1.12–12.75

Table 3 Pearson correlation coefficient between heavy metals

	Fe	Pb	Cu	Mn	Cr	Zn	K
Fe	1						
Pb	.161	1					
Cu	.429**	.157	1				
Mn	.517**	.489**	.405**	1			
Cr	.004	−.030	.101	−.069	1		
Zn	.112	.593**	.042	.509**	−.128	1	
K	.194	.198	.052	.300*	−.093	.300*	1

* $p < 0.05$

** $p < 0.001$

as traffic movement (especially, see [11]), industries and agricultural activities have been constructed.

The relationships between heavy metals in soil have been determined using the Pearson correlation coefficients (see Table 3). Table 3 has shown that there are strong interactions between Mn and Fe, Pb, Cu and between Zn and Pb, Mn. In addition, the relation between Cu and Fe are also observed. All of correlations between heavy metals are positive in soil samples.

Conclusion

The results are very important due to the first and unique study, according to our best knowledge, in this fault system. In this work we have investigated distribution of natural radioactivity concentration (gross alpha and beta) in water and heavy metals in soil of a seismically active area apart of East and North of Turkey. The highest concentration of heavy metals was found for Mn element. The gross-alpha activity concentrations of water samples are high when compared with gross-beta activity concentration. Comparatively high mean value of gross-alpha radioactivity concentration of studied region may be due to the presence of lineaments/faults in the area. The clear relationships between radioactivity concentration and heavy metal content of soil in tectonically active area have not been observed.

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