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A study about radiation dosimetry and heavy metal pollution in the Küçük Menderes Basin, Turkey (Radio-ecological and Heavy Metal Risks)

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Abstract

Agricultural researchers in many countries investigate radiological risks in soil and crops because it concerns human health. In addition, they also study heavy metal pollution in plants in cultivated soil for ecological safety. This study aims to analyze the activity concentrations of radionuclides and heavy metals in soil and corn crops in the Küçük Menderes Basin (Izmir, Turkey) – which is enriched with phosphatic fertilizers. We collected soil and corn samples from the area, and then separately measured concentrations of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) and trace elements (Cd, Cr, Cu, Hg, Ni, Pb and Zn) they contain. Activity concentrations of the radionuclides were acquired by radiometric methods (gamma spectroscopy). Heavy metal amounts were calculated using ICP-MS (inductively coupled plasma-mass-spectrometry). The mean heavy metal concentrations in the soil (Cd, Cr, Cu, Zn, Ni, Pb, Hg) were 0.096, 40.26, 26.51, 72.43, 32.24, 7.05 mg kg^{-1}, 158.28 µg kg^{-1} and in the corn (Cd, Cr, Cu, Zn, Ni, Pb, Hg) were 0.01, 1.09, 2.05, 22.00, 0.54, 0.24 mg kg^{-1}, 12.15 µg kg^{-1}. The heavy metal concentrations in soil samples were as follows: Hg<Cd< Pb<Cu<Ni<Cr< Zn and in corn samples were as follows: Hg<Cd<Pb<Ni<Cr<Cu<Zn. Also, the mean activity concentrations in the soils (^{226}Ra, ^{232}Th, ^{40}K) were 36.2±2, 32±1, 615.44±7 Bq kg^{-1}. The ^{226}Ra and ^{232}Th concentrations in the corn samples are smaller than the Minimum Detectable Activity (MDA). However, the mean activity concentration of ^{40}K in the corn samples is 310.7±8 Bq kg^{-1}. These values considered are acceptable for human health according to UNSCEAR (2000). The heavy metal concentrations in the soil and corn samples are within acceptable limits for Turkish Government. The level of radionuclide activity and heavy metal concentrations, as well as both transfer and bio-concentration factors are comparable with those of a handful of other countries. Long-term research on radio-ecological risks is very important for agricultural control. In addition, the data set of radiation levels and pollutant elements do not have a fixed amount in related materials such as soil and plants. On the other hand, the quantity of pollutants soil (via plants) has risen due to activity from non-controlled industrial facilities. Researchers and governments alike therefore must monitor ecological pollution of terrestrial radionuclides and heavy elements on a routine basis.

Keywords: Radioecology, agronomy, heavy metals, soil, corn.

Introduction

In recent years, many radio-ecological studies have focused on the deposition of radionuclides in different ecosystems (Kuo et al., 1997; dos Santos Amaral et al., 2005; Abbady et al., 2005; Bolca et al., 2007; Yadav et al., 2017). It takes longer for soil in nature and semi-natural eco-systems to absorb radionuclides than it does cultivated soil. Many environmental factors affect the horizontal distribution of radionuclides in the soil: namely change in topography, falling, and wind. Furthermore, local plant flora alongside animal movement

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(surface or underground) also can biologically affect how radionuclides get distributed. Radionuclides reach the plant roots and enter the food chain via vertical distribution. Moreover, they can mix into ground- and drinking water (Epik, 2005). According to UNSCEAR (2000a,b), gamma radiation from ^{238}U and ^{232}Th series and from ^{40}K can exist inter-bodily; gamma irradiation – like beta and alpha irradiation – can occur in all organs like. This in turn leads people to develop inescapable health problems such as cancer (Kapdan et al., 2018). The world-mean values for ^{226}Ra, ^{232}Th, and ^{40}K activity concentrations (including their deviation intervals) in soil are 35 Bq kg^{-1} (17-60), 30 Bq kg^{-1} (11-64), and 400 Bq kg^{-1} (140-850), respectively (UNSCEAR, 1988). The now extensive use of phosphatic fertilizer by farmers has caused natural radionuclide concentrations to increase in soil, and thus agricultural products (Khalf and Mohammad, 2021; Sallam et al., 2021).

Terrestrial ^{238}U and its daughter products are at radioactive equilibrium in phosphate rocks. Its radioactive equilibrium breaks down during industrial processing and creates ^{238}U, ^{226}Ra, ^{210}Pb and ^{210}Po radionuclides in industrial by-products. Therefore, phosphatic fertilizer is an important of source of TENORM (Technologically Enhanced Naturally Occurring Radioactive Materials). One might deem this a radio-ecological risk (Camgöz and Yaprak, 2009). The annual effective dose equivalent (per person) for phosphate production is 0.04 µSv in industrial applications, 2 µSv in fertilizer, and 10 µSv in phosphate waste (UNSCEAR, 1993). Processing phosphate rocks and using them in various areas of industry creates TENORM. They also are an important source of energy (via coal and other fossil fuels) and radioactive minerals. The radiation dose from industrial activities is 100 µSv. This is very small in comparison with natural radiation (UNSCEAR, 2000a,b).

Heavy metals concentrations in cultivated soil depend on geologic construction. Heavy metal concentrations have been identified in the Earth's crust (Carnelo et al., 1997) – namely Cd, Cr, Cu, Ni, Pb and Zn at 0.5, 200, 100, 80, 16 and 50 mg kg^{-1}, respectively. However, fertilization, atmospheric deposition, agricultural chemicals, industrial, household (namely organic) waste, and other inorganic sources of pollution (ore bed and mine waste) cause soil to accumulate heavy metals (Taşkaya, 2004). Phosphatic fertilizers made from phosphate rocks incorporate several heavy metals (Co, Cu, Fe, Mn, Mo, Ni, Zn), Fluorine, and toxic metals (As, Al, Cd, Pb and Hg), alongside radioactive elements (Camgöz and Yaprak, 2009). Extensively using phosphatic fertilizers can increase how much Fluorine, heavy metals, and radioactive elements soil – and thus plants – absorb. Both organic and phosphatic fertilizers (can) cause soil to accumulate heavy metals such as Zn, Cu, and Cd.

Plants enhance radioactivity in soil by absorbing radionuclides via their roots or by means of surface deposition due to atmospheric precipitation. They absorb heavy metals and radionuclides through the soil from water, salt, and minerals. However, plants will recycle those radionuclides back into soil. The rate at which plants absorb radioelements and other chemicals by plants depends on how productive the soil is, how acidic/alkaline and reductive - oxidative agents in soil are, and its organic composition (Grytsyuk et al., 2006). This rate for radioactivity absorption is defined as the transfer factor (TF) or the rate at which radionuclide penetrates the crop via contaminated soil (Alharbi and El-Taher, 2013). TF is calculated the ratio of radionuclide concentrations in crops (Bq kg^{-1} dry mass) to concentration of radionuclides in soil (Bq kg^{-1} dry mass) (Vandenhove et al., 2009). TF is a prediction indicator for risk to human health risk because of how many radionuclides gets transferred into the food chain (Tome et al., 2003; Ali et al., 2020). The bio-concentration factor (BCF) is trace element concentration in crop tissues (mg g^{-1}) over the background concentration of metals in the soil (mg g^{-1}) (Tiwari et al., 2011). It quantifies the bioavailability of heavy metals in agricultural products. (Kim et al., 2012). Soil-to-plant transfer exposes humans to heavy metals. The health risks associated with heavy metal contaminations from soil to agricultural food has been widely studied (Cui et al., 2004).

This study investigates the possible pollution of radionuclides and heavy elements by assessing the terrestrial gamma doses rate in agricultural soil and corn samples taken from Küçük Menderes Basin. This study is local in nature. That noted, while local databases are important for environmental efforts, every local study area is nevertheless can serve research in neighboring countries – give or take variation in atmospheric activity and ground transfer rates. One can in turn use such data for comparison purposes and to track environmental relationships.

Why are environmental radiometric studies important? While they may not offer us improved techniques or new fundamental approaches, their data nonetheless contains important data – especially where agricultural product trade between countries is concerned, namely when it comes to government procedures and people requesting product information for health purposes. Environmental studies can supply this. One should consider case studies as a scientific database case.

Material and Methods

The Küçük Menderes Basin is an important agricultural area in western Turkey for corn farming. Farmers there moreover make extensive use of phosphatic fertilizers. Its geographical position of the basin that feeds into is 38º41´05'' by 37º53´08'' N (latitude) and 28º41´36'' and 26º11´48'' E (longitude). This basin forms Küçük Menderes's quaternary sediment filling graben (broken in the Menderes Massif). That filling is composed of crystalline rocks; the basin likewise covers a broad surface area (Dora et al., 1992). We collected raw soil samples (55) as well as those from principal crops (13) (where crop roots grow) from various points along the basin (Figure 1 and 2).

Figure 1. Soil sample points in Küçük Menderes Basin (maps.google.com)

Figure 2. Corn sample points in Küçük Menderes Basin (maps.google.com)

First, we marked every point of each soil sample (3 kg), sifted them, left them to dry under the sun for three days, and then baked them in an 105°C degree oven for between two and forty eight until they reached a constant weight. Next, the dried and homogenized soil samples were placed into Marinelli beakers (1 L). Corn is classic product grown around the basin. As such, we collected and air-dried samples (at 105°C for a few days) of corn grains until they reached a constant weight. We then ground the corn grain down and filled it into 100 cc plastic containers. Each sample was sealed and stored for four weeks in order to study their secular radioactive equilibriums between ^{226}Ra and ^{222}Rn.

We identified ^{226}Ra, ^{232}Th and ^{40}K in the samples using gamma spectroscopy. Analytical quality control of both gamma spectrometer systems done by using standards prepared from IAEA and Amersham-sourced reference materials whose matrices and geometries were similar to the samples. We used two types of detectors due to how much of each sample there was. We used one-liter Marinelli Beakers on the HPGe detector system (184 cc HPGe coaxial, efficiency: 25%, for 1.33 MeV ^{60}Co FWHM: 1.83 keV and peak/Compton; 57:1, Ortec Model-671 amplifier and Canberra PC base MCA (8K) Wilkonson ADC, 100 mm shielding). The HPGe detector has good resolution however, it does not have enough efficiency in some conditions, especially for low activities. The lower detection limits were 2 Bq/kg for ^{226}Ra, 1 Bq/kg for ^{232}Th and 4 Bq/kg for ^{40}K. As the plant samples were limited in terms of both quantity and volume, we thus needed high efficiency more than resolution. Therefore, we turned to a NaI (Tl) scintillation gamma spectrometer (Tennelec 3" X 3" NaI (Tl) detector (shielded with 50 mm lead) as well as a computer-based multi-channel analyzer) to examine the corn samples.

Due to the limited separation efficiency of NaI (Tl) scintillation detectors, the gamma energies (2.6 MeV, 1.76 MeV, 1.46 MeV) that we had selected for these primordial radionuclides could not directly be used to measure the concentrations by scintillation gamma spectroscopy. The lower detection limits were 1 Bq/kg for ^{238}U, 1 Bq/kg for ^{232}Th and 5 Bq/kg for ^{40}K (Canbaz Öztürk, 2015). One therefore must calculate how each radionuclide contributes to one another according to the appropriate factors. To resolve this, we used the following three equations (Akakçe, 2008):

$$^{232}\text{Th (Bq kg}^{-1}) = \frac{C(\text{Th})}{K_1}\alpha \quad (1)$$

$$^{238}\text{U (Bq kg}^{-1}) = \frac{1}{K_2}[C(U) - \alpha C(\text{Th})] \quad (2)$$

$$^{40}\text{K (Bq kg}^{-1}) = \frac{1}{K_3}[C(K) - \gamma[C(U)] - \alpha C(\text{Th}) - \beta C(\text{Th})] \quad (3)$$

K_1, K_2, and K_3 constitute sensitivity factors – i.e. count rates per unit activity concentration (IAEA, 2003). The method for both how we determined the stripping rates (α, β and γ) that gave us these additive rates (depending on the geometry and various settings of the spectrometer), and how we found out the sensitivity factors that enable the transition from net counts to activity concentration in terms of K (%), U (mg kg^{-1}), Th (mg kg^{-1}) was as follows.

K_1= 6.2 counts/ 10000s per Bq/kg ^{232}Th
K_2= 7.3 counts/ 10000s per Bq/kg ^{238}U
K_3= 2.4 counts/ 10000s per Bq/kg ^{40}K

The stripping rates of the gamma spectroscopy system were $\alpha = 0.75$, $\beta = 0.81$, and $\gamma = 1.32$, respectively.

According to UNSCEAR (1993), the equation to determine the terrestrial gamma dose rate in soil is:

$$D \text{ (nGY h}^{-1}) = 0.461\, C_{Ra} + 0.623\, C_{Th} + 0.0414\, C_K \quad (4)$$

C_{Ra}, C_{Th} and C_K are concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

We ground the dried corn and soil samples (5 g) at Dokuz Eylül University's Geology Engineering Lab (Retsch (RS 100)), and then measured all of the heavy metal levels in them at the ACME Analytic Lab. (ISO-9002) for analysing inductively coupled plasma-mass- spectrometer (ICP-MS). All analytical results of soil and corn in microwave extraction were obtained in mg/kg and µg/kg as well as for the laboratory's internal reference materials DS7 and NMKL186 inserted in parallel. Interference possibilities were evaluated by isotopic analysis. Heavy metal and radionuclide distribution were mapped on Surfer 8.0 (free demo version).

Results and Discussion

Radioelement and heavy metal data in soil and agricultural crops are largely based on how much background radiation there is in the soil, climatic factors, and present agricultural applications. We calculated concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in 20 cm-deep cultivated soil samples as well. The mean of radionuclide activity concentrations in them were 36.2±2 Bq kg^{-1} (^{226}Ra), 32±1 Bq kg^{-1} (^{232}Th), and 615.44±7 Bq kg^{-1} (^{40}K). The mean terrestrial gamma dose rate was 62.1 nGy h^{-1}. We did not look at the activity concentrations of ^{226}Ra and ^{232}Th in any of the corn samples because they were below MDA (minimum detectable activity) and thus would not have been detected on a NaI (Tl) scintillation detector. However, there were nondedectable (ND) activities of U and Th in the corn. In contrast, the ^{40}K concentrations in the corn samples ranged between 136±8 and 712±7 Bq kg^{-1} (mean 310.7±8 Bq kg^{-1}).

We measured the concentrations of Cd, Cr, Cu, Hg, Ni, Pb, and Zn in both the soil and corn samples on an ICP-MS. What we discovered was that the Küçük Menderes Basin contains Cd 0.096 (0.01-0.21) mg kg^{-1}, Cr 40.26 (17.60-69.80) mg kg^{-1}, Cu 26.51 (9.45-58.01) mg kg^{-1}, Ni 32.24 (17.20-53.40) mg kg^{-1}, Pb 7.05 (3.53-12.57) mg kg^{-1}, Hg 158.28 (4.00-920.00) µg kg^{-1}, and Zn 72.43 (35.70-106.90) mg kg^{-1}. Also, mean heavy metal concentrations in its soil from highest to lowest were Zn>Cr>Ni>Cu>Pb>Cd>Hg. The heavy concentrations of Cd, Cr, Cu, Zn, Ni, Pb, and Hg in the corn samples were ~ 0.01 (<0.01-0.02), 1.09 (0.90-1.30), 2.05 (1.14-6.44), 22.0 (13.4-40.60), 0.54 (0.20-1.70), 0.24 (0.14-0.63) mg kg^{-1} and 12.15 (1.00-30.00) µg kg^{-1} (Zn>Cu>Cr>Ni> Pb>Cd>Hg), respectively.

The mean activity concentrations of ^{226}Ra and ^{232}Th did not exceed UNSCEAR (2000a,b) standards (Table 1). However, ^{40}K activity concentration exceeded global average in the basin's surface soil due to farmers intensive cultivation activities and because they extensively use fertilizers containing phosphate. Nevertheless, in 75% of the basin samples, activity concentrations of ^{40}K fell below the maximum of concentrations for natural soil in UNSCEAR (2000a,b).

Table1. Comparable radionuclide activity concentrations (Bq kg^{-1}) in soil

Country	^{226}Ra	^{232}Th	^{40}K	References
Australia	-	36 (1-342)	325 (2-1132)	(Kleinschmidt, 2017)
Nigeria	205.08	103.19	350.75	(Gbadamosi et al,. 2018)
Iraq	247	24.86	293.70	(Ridha et al., 2015)
India	41	32.3	544.7	(Yadav et al., 2017)
Serbia	40.6	48	743.2	(Gulan et al., 2013)
Greece	20-710	21 (1-193)	355 (12-1570)	(Anagnostakis et al., 1996)
Greece	21-80	16-85	337-1380	(Florou and Kritidis, 1992)
Greece	7-310	3-190	30-1440	(Probonas and Kritidis, 1993)
Greece	25 (1-238)	21 (1-193)	355 (12-1570)	(Anagnostakis et al., 1996)
Ireland	-	3-60	40-800	(McAulay and Morgan, 1988)
Italy	57-71	73-87	580-760	(Bella et al., 1997)
Norway	43.3 (12-137)	21.1 (4-52)	283 (31-564)	(Dowdall et al., 2003)
Serbia	21-29	25-43	348-441	(Djuric et al., 1996)
Spain	13-165	7-204	48-1586	(Baeza et al., 1992)
Spain	38.3 (36.2-40.59)	41(38.9-43.7)	653 (617-689)	(Baeza et al., 1992)
Spain	8-310	5-258	31-2040	(Quindos et al., 1994)
Turkey (Küçük Menderes Basin)	36.2±2 (13±2-58±2)	32±1 (12±1-74±1)	615.44±7 (72±7-1119±7)	This study
World	17-60	11-64	140-850	(UNSCEAR, 2000a,b)

The measured highest activity concentration of ^{226}Ra is 58±2 Bq kg^{-1} on the soil surface. As is seen in Figure 3, ^{226}Ra concentrations rise towards the east of basin. Also, the distribution map shows a spike in ^{232}Th radionuclides northeast (Kiraz district) and southwest (Selçuk district) of the basin at a maximum value worth 74±3 Bq kg^{-1} (Figure 4). In soil, ^{40}K distribution is homogeneous throughout the basin (Figure 5). The highest activity concentration of ^{40}K we found was 1119±11 Bq kg^{-1} in the Kiraz district.

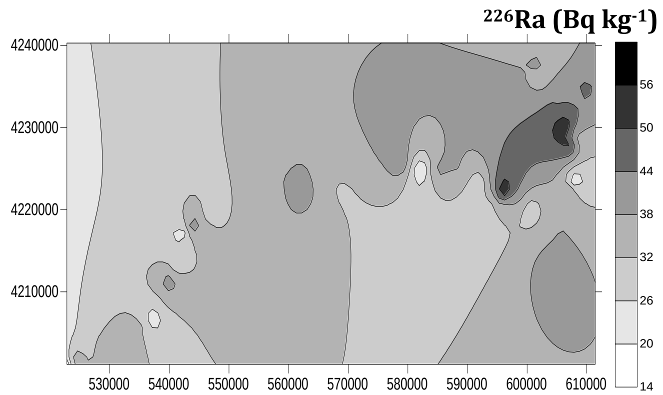

Figure 3. Distribution of ^{226}Ra concentration in soil (UTM)

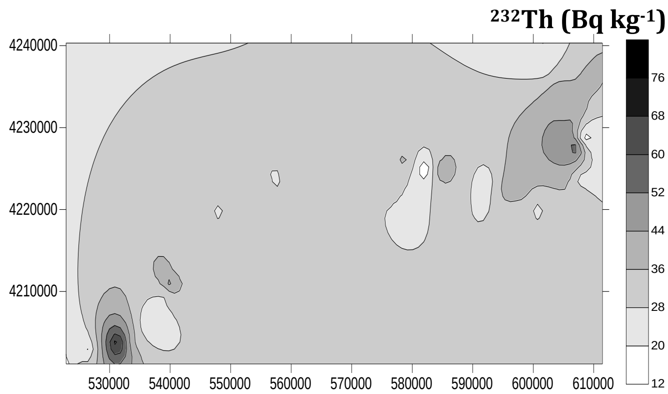

Figure 4. Distribution of ^{232}Th concentration in soil (UTM)

Figure 6 shows us that mean terrestrial gamma dose not exceeded UNSCEAR (2000a,b) standards [60 (20-200) nGy h^{-1}]. As one can see in Table 2, radionuclide concentrations in our corn samples are very low compared to grain crops. Potassium (K) is a "quality element" in crop production. A lack of K can disrupt enzyme system functions, photosynthesis, respiration, growth, and translocation. Potassium fertilization likewise affects corn grain quality (Usherwood, 1985). Generally speaking, radioelement concentrations (excluding ^{40}K) in grain crops are low at best. ^{40}K isotope is very for plant nutrition. The transfer factor of ^{40}K is very small (~10^{-4}) from soil to grain crops (Yaprak et al., 1998). ^{226}Ra, ^{232}Th and ^{40}K concentrations in grain crops varies from country to country (Table 2). ^{40}K activity concentration usually exceeds other radionuclides (^{226}Ra and ^{232}Th). We discovered that corn samples hailing from Izmir's Tire and Ödemiş districts contained the highest quantity of ^{40}K, whist those from the Torbalı district had the least (Figure 7).

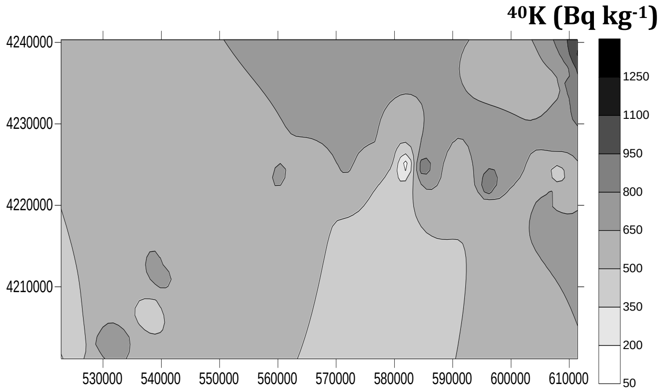

Figure 5. Distribution of ^{40}K concentration in soil (UTM)

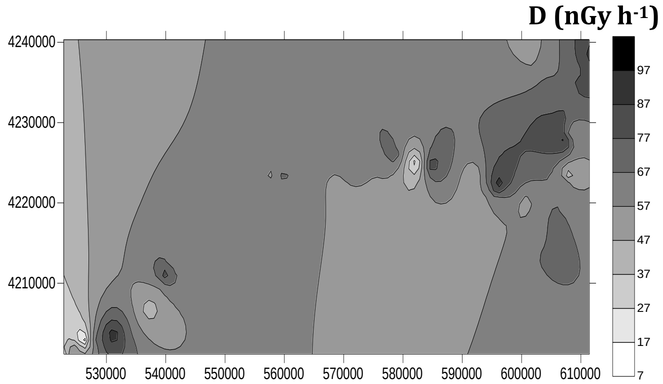

Figure 6. Terrestrial gamma dose rate (nGY h^{-1}) in soil (UTM)

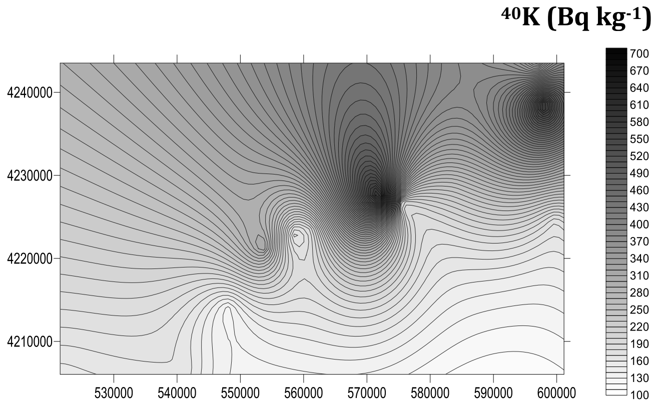

Figure 7. Distribution of ^{40}K concentration in corn samples (UTM)

Table 2. Radionuclide activity concentrations in grain crops in some countries

Plant	**Radionuclide Activity Concentrations (Bq kg^{-1})**			**Area**	**References**
	^{226}Ra	**^{232}Th**	**^{40}K**		
			Grain Crops		
Bean	0.748	-	-	Pernambuco, Brazil	(dos Santos Amaral et al., 2005)
	0.6	12.8	110.5	Upper Egypt	(Abbady et al., 2005)
Soy	8.3	ND	546.8	Jos Plateau, Nigeria	(Jibiri et al., 2007)
	≤4.3	-	745	Parana State, Brazil	(Scheibel and Appoloni, 2007)
Corn	0.13	-	-	Pernambuco, Brazil	(dos Santos Amaral et al., 2005)
	34.1	ND	243.2	Jos Plateau, Nigeria	(Jibiri et al., 2007)
	25.82	ND	491.62	Gediz Basin, Turkey	(Bolca et al., 2007)
	ND	ND	310.7±8 (136±8-712±7)	Küçük Menderes Basin, Turkey	This study
Sesame	2.5	11.5	125.5	Upper Egypt	(Abbady et al., 2005)
Wheat	3.4	9.7	104.8	Upper Egypt	(Abbady et al., 2005)
	0.04–0.37	0.015–0.11	111.3–245.7	India	(Yadav et al., 2017)
Rice	0.08	-	-	Taiwan	(Kuo et al., 1997)
Lentil	2.1	16.1	176.1	Upper Egypt	(Abbady et al., 2005)

When we compare radionuclide concentrations from other countries and regions of Turkey, we see that (Table 2), ^{40}K concentrations in the corn crops can reach as high as 243.20 Bq kg^{-1} (in Nigeria) and 491.62 Bq kg^{-1} (in the Gediz Basin, Turkey). In Izmir, the ^{40}K activity concentration value has been calculated as 310.7 Bq kg^{-1} (Table 2). ^{226}Ra concentrations in corn range from 0.13 Bq kg^{-1} in Brazil, to 25.82 Bq kg^{-1} in the Gediz Basin (Turkey) and 34.1 Bq kg^{-1} in Nigeria (Table 2). ^{232}Th concentrations in corn in Serbia is <0.2 Bq kg^{-1} – this is very low for a basin area. UNSCEAR (2000a,b) reference values in grain products are 80 Bq kg^{-1} (^{226}Ra), 20 Bq kg^{-1} (^{238}U), and 1 Bq kg^{-1} (^{232}Th). Our values (ND for ^{238}U and ^{232}Th) are below UNSCEAR (2000a,b)'s standards. ^{40}K activity concentration in this study (in Izmir) is lower than of other countries. However, the activity concentration found in the Gediz Basin is higher than literature data. Likewise, researchers have that ^{40}K in lentil, wheat, sesame, and bean crops are low, whilst in soy it is high. In India, ^{232}Th concentrations in wheat were found to be particularly low (Table 2).

In this study, we found that the TF of ^{232}Th and ^{226}Ra from soil to corn were almost zero. In contrast, the TF of radionuclides in most grain crops is ~10^{-4}, with the exception of ^{40}K (Yaprak et al., 1998). Our findings reveal that the mean TF of ^{40}K was 0.504 According to IAEA Report TRS 472 (2011), the transfer factor of K in grain cereals is 0.74. The TF of Ra, U and Th in grain maize are 2.4 10^{-3}, 1.5 10^{-2} and 6.4 10^{-5}, respectively. Alharbi and A. El-Taher (2013) discovered that of TF of ^{40}K from soil to alfalfa, wheat grains, and palm dates was 0.094, 0.16, and 0.22. They also also discovered that mean TF of ^{226}Ra from soil the same three items was 0.14, 0.12, and 0.12, respectively. Researchers in north-western Saudi Arabia obtained the soil-to-plant transfer factors of ^{226}Ra, ^{234}U and ^{238}U for crop plants in the range 0.07 ± 0.01 to 0.71 ± 0.15, 0.12 ± 0.02 to 0.44 ± 0.10, and 0.11 ± 0.02 to 0.40 ± 0.08 (Al-Hamarneh et al., 2016). Vandenhove et al., (2009) investigated TF of U, Th, ^{226}Ra, ^{210}Po, ^{210}Pb for maize respectively. Their findings: 0.121, 8.45 10^{-4}, 0.01, 1.68 10^{-3} and 2.42 10^{-4}. Spanish researchers found the transfer factors (TF) for ^{238}U, ^{234}U, ^{232}Th, ^{230}Th, ^{228}Th, and ^{226}Ra in grass samples taken from a region in south-western Spain were: 0.067, 0.072, 0.058, 0.056, 1.6, and 0.17 (Tome et al., 2003). Our TF values are similar to the literature.

In Table 3, one can see that heavy metal concentrations in our soil samples are very low relative to the Earth's crust. The same holds true when we compare them with EU Commission standards. We compared our values with those of other parts of the world (Table 3), namely: Kolkata (a disposal area), Vientiane (which receives > 300 tons of waste daily), Paramillo Massif (affected by mining areas upstream and inundated during seasonal floods), Peloponnese (that maintained uncontrolled application rates of fertilizers and pesticides–fungicides), South-west Nigeria (around a mega cement factory), Dhaka (around the Dhaka Export Processing Zone (DEPZ)), Gilgit (surrounded by volcanic rocks). All of the above sites exhibited higher levels of heavy metals than Küçük Menderes Basin (Table 3).

Table 3. Heavy metal concentration (mg kg^{-1}) in soil in some countries

Cd	Cr	Cu	Hg	Ni	Pb	Zn	Area	References
0.238	31.02	20.89	0.126	9.95	53.44	79.87	Jiedong District, China	(Jiang et al., 2020)
-	309	379	7	-	378	844	Kolkata, India	(Mukhopadhyay et al., 2020)
3.73	48.08	54.06	-	19.94	67.99	52.48	Vientiane, Laos	(Vongdala et al., 2019)
-	-	784.9	-	-	82.4	166.5	Kajaran, Armenia	(Tepanosyan et al., 2018)
0.008	-	118.1	0.028	14.1	0.012	107	Paramillo Massif, Colombia	Marrugo-Negrete et al., 2017)
0.09	21.72	13.01	0.004	18.36	15.3	-	EU countries	(Tóth et al., 2016)
1.48	-	17.18	-	88.7	28.9	34.94	Çanakkale, Turkey	(Sungur et al., 2014)
0.54	83.12	74.68	-	146.8	19.74	74.88	Peloponnese, Greece	(Kelepertzis, 2014)
547.9	156.6	613.4	-	-	666.1	188.5	Southwest Nigeria	(Ogunkunle and Fatoba, 2013)
0.0072	49.66	60.0	486.6	48.1	27.6	209	Dhaka, Bangladesh	(Rahman et al. 2012)
0.3-2.3	-	55-147	-	24-57	29-138	137-1194	Gilgit,Pakistan	(Khan et al., 2010)
1.5	-	100	-	70	100	200	EU Commission standard	(EU, 2000)
0.5	200	100	-	80	16	50	Earth crust	(Camelo et al., 1997)
0.096	40.26	26.51	158.28*	32.24	7.05	72.43	Küçük Menderes Basin, Turkey	This study

*µg kg^{-1}

As one can see in Figures 8, 9, and 10, we found Cd (0.21 mg kg^{-1}), Cr (69.80 mg kg^{-1}) and Cu (58.01 mg kg^{-1}) concentrations reaching maximum value in the districts of Kiraz and Tire. We also found Ni (53.40 mg kg^{-1}) and Pb (12.57 mg kg^{-1}) at the center of Tire (Figure 12-13). Figures 11 through 14 shows us the highest amounts Hg (920 µg kg^{-1}) and Zn (106.9 mg kg^{-1}) are concentrated in the districts of Belevi and Selçuk. Heavy metal concentrations commonly are observed in settlements and industrial areas, but minimum concentrations of heavy metals are determined from riverhead to Kiraz district.

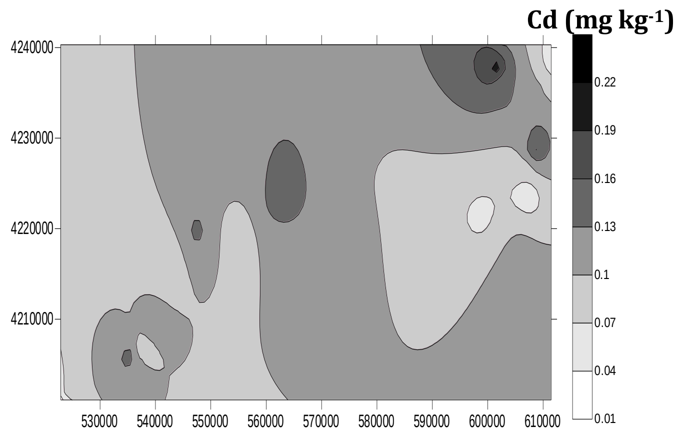

Figure 8. Concentration of Cd (mg kg^{-1}) in soil (UTM)

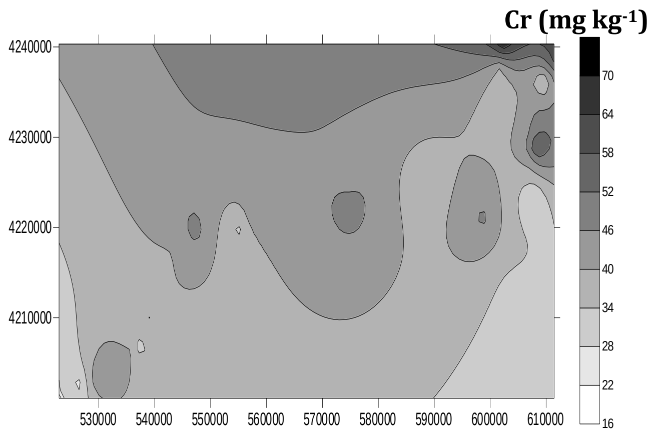

Figure 9. Concentration of Cr (mg kg^{-1}) in soil (UTM)

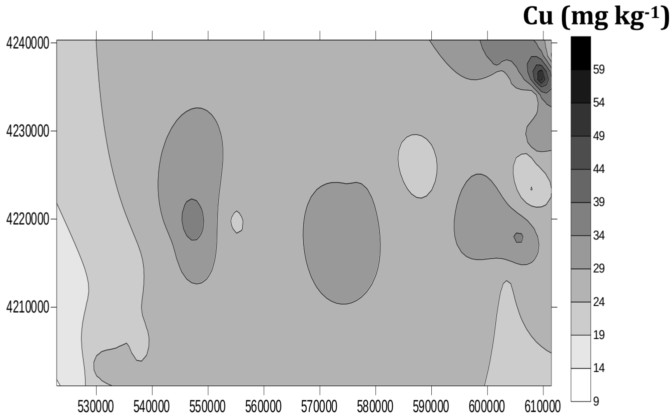

Figure 10. Concentration of Cu (mg kg-1) in soil (UTM)

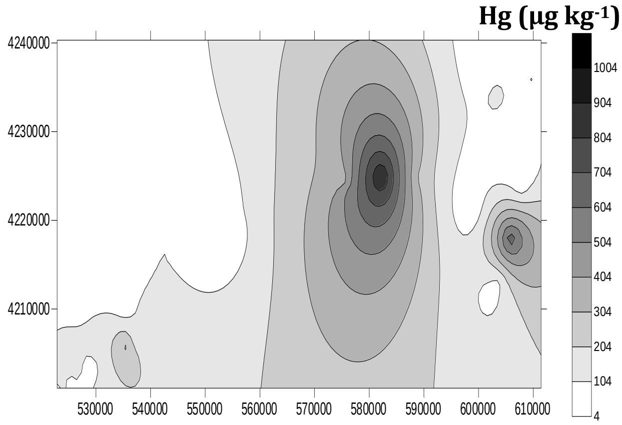

Figure 11. Concentration of Hg (µg kg-1) in soil (UTM)

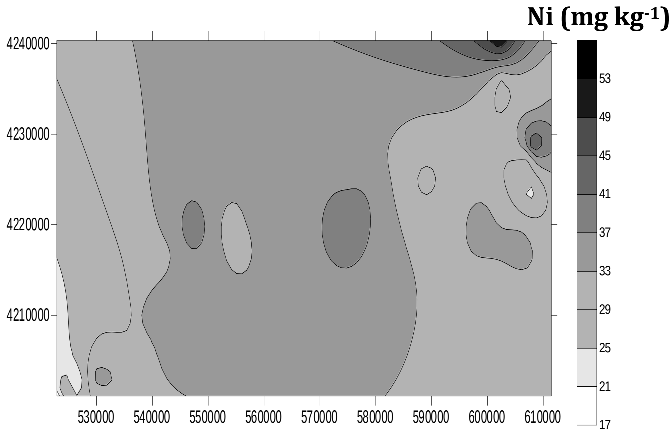

Figure 12. Concentration of Ni (mg kg-1) in soil (UTM)

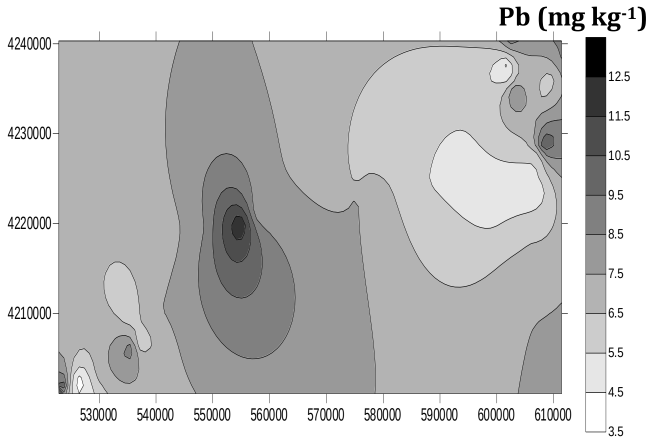

Figure 13. Concentration of Pb (mg kg-1) in soil (UTM)

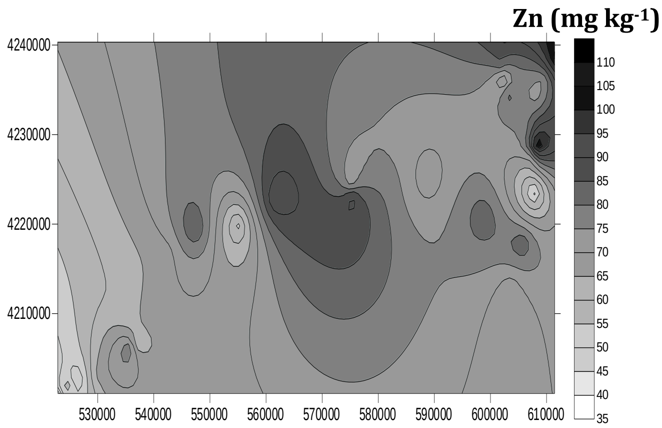

Figure 14. Concentration of Zn (mg kg-1) in soil (UTM)

According to Table 4, we see that Cd, Cr, Cu, Pb and Zn concentrations in corn samples from Serbia are lower than ours, where as their Hg and Ni concentrations are higher than ours (Table 4). Cd, Cu, Pb and Zn concentrations in corn samples from China as well as Cu, Ni and Pb concentrations in corn samples from Argentina are also vary compared to what they are in our findings (Table 4). According to Turkish Ministry of Environment and Forestry, the limit of heavy metals (Pb, Cd, Cr, Cu, Ni, Zn, Hg) are respectively 50.00, 1.00, 100.00, 50.00, 30.00, 150.00, 1.00 mg kg^{-1} (Çevre ve Orman Bakanlığı, 2005). Our heavy metal values in the soil samples are below the limits of Turkish Ministry of Environment and Forestry.

Our findings demonstrate that the highest amount of Cd, Ni, and Zn in our corn samples hailed from the districts of Ödemiş and Kiraz – 0.02 mg kg^{-1}, 0.63 mg kg^{-1}, and 40.6 mg kg^{-1}, respectively (Figure 15, 19, 21). We observed that those corn samples from the districts of Selçuk and Torbalı likewise had the highest concentrations of Cr (1.3 mg kg^{-1}) and Cu (6.44 mg kg^{-1}) among the rest of the samples (Figure 16, 17). Hg concentrations reached 30 µg kg^{-1} in corn from Bayındır district (Figure 18). Pb concentrations reached 0.63 mg kg^{-1} in corn from Ödemiş district (Figure 20). According to Turkish Food Codex Regulation on Contaminations (Gıda, Tarım ve Hayvancılık Bakanlığı, 2012), the permitted limit of Pb level in corn (wet weight) is 0.10 mg kg^{-1} and, of Cd level in grain crops (except rice) is 0.10 mg kg^{-1}. Both Pb and Cd concentrations of corn samples are within the limits of Turkish Food Codex Regulation on Contaminations.

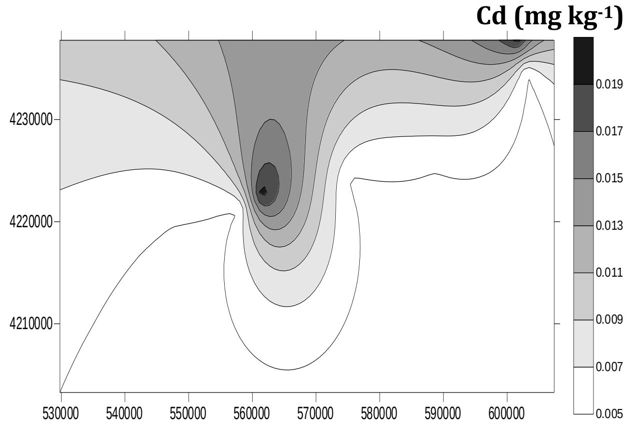

Figure 15. Concentration of Cd (mg kg^{-1}) in corn (UTM)

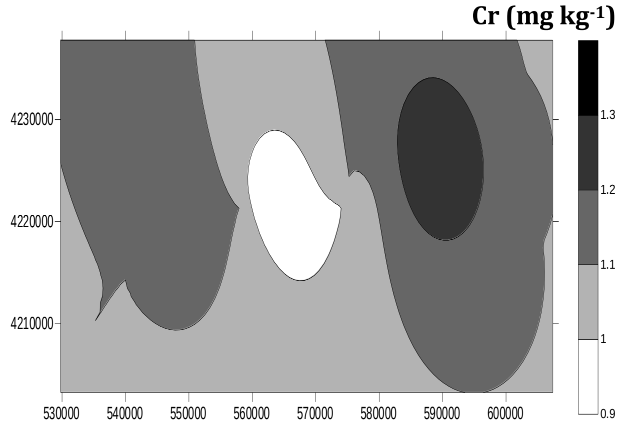

Figure 16. Concentration of Cr (mg kg^{-1}) in corn (UTM)

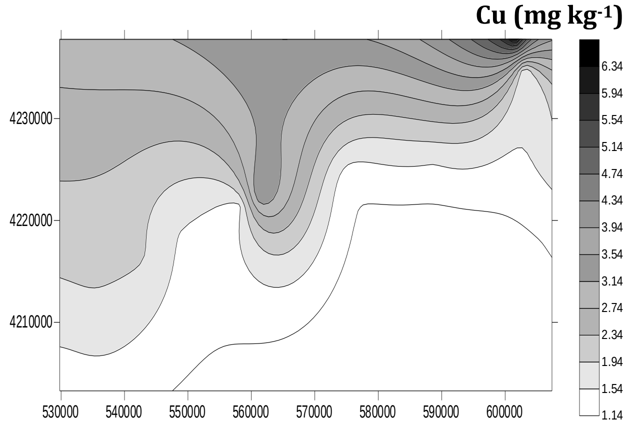

Figure 17. Concentration of Cu (mg kg-1) in corn (UTM)

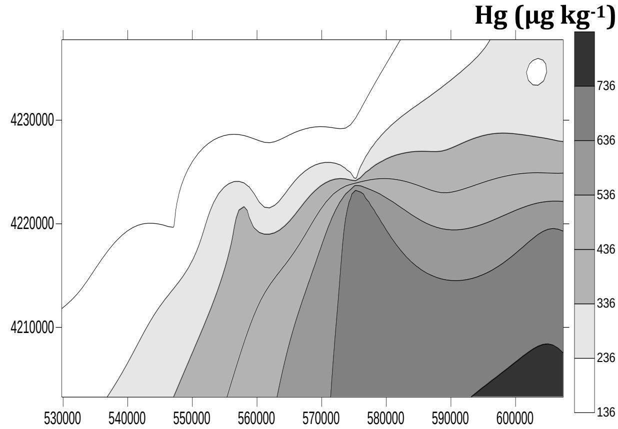

Figure 18. Concentration of Hg (µg kg^{-1}) in corn (UTM)

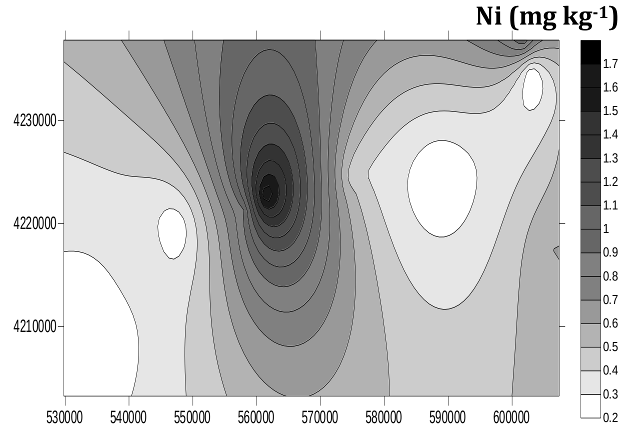

Figure 19. Concentration of Ni (mg kg^{-1}) in corn (UTM)

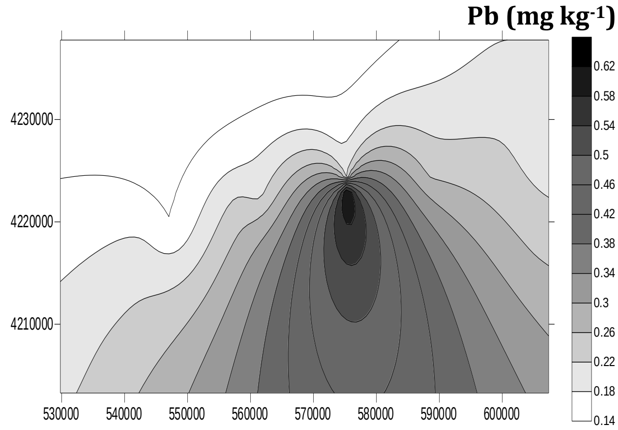

Figure 20. Concentration of Pb (mg kg-1) in corn (UTM)

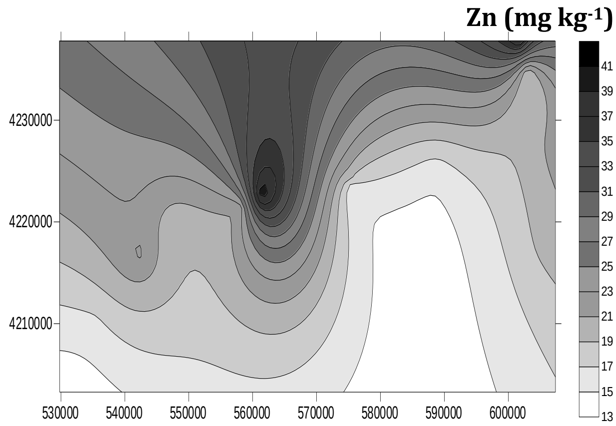

Figure 21. Concentration of Zn (mg kg^{-1}) in corn (UTM)

Table 4. Heavy metal concentration in corn crops in some countries

Heavy Metal Concentrations (mg kg^{-1})								
Cd	Cr	Cu	Hg	Ni	Pb	Zn	Area	References
<0.05	1.23	10.30	-	0.87	0.80	19.09	Pampas, Argentina	(Lavado et al., 2001)
0.03	-	6.71	-	-	0.29	51.57	Hunan,China	(Liu et al., 2005)
<0.10	0.60	1.80	0.02	0.80	1.60	20.00	Serbia	(Jakovljevic et al., 1997)
0.01	1.09	2.05	12.15*	0.54	0.24	22.00	Küçük Menderes Basin, Turkey	This study

*µg kg^{-1}

BCF in Pb, Cd, Cr, Cu, Ni, Zn and Hg was found in corn samples at the following means, worth: 0.035, 0.105, 0.026, 0.077, 0.016, 0.296 and 0.086, respectively. The IAEA Report TRS 472 (2011) indicates that the transfer factor in grain cereals for Ni and Cr are 2.7 10^{-2} and 2.0 10^{-4}. It also indicates that transfer factor of grain maize for Cd, Pb and Zn are 0.05, 1.2 10^{-3} and 0.58. Researchers found TF values in Cd, Zn, Pb and Cu for vegetables from Nanning, Southern China to be (0.001-1.83), (0.021-0.507), (0-0.031), (0.017-0.35) (Cui et al., 2004). South Korean has researchers investigated soil to corn BCF discovered figures worth 0.51 (As), 0.11 (Cd), and 2.54 (Pb) (Kim et al., 2012). Tome et al. (2003) found BCF values for Al, Cr, Cu, Fe, K, Mn, and Zn in plants worth 0.055, 0.03, 0.68, 0.088, 0.42, 1.4, and 1.1. BCF in various plants. Our BCF data is similar to Cui et al. (2004)'s and lower than Tome et al. (2003)'s findings.

Conclusion

In this study concentrations of radioactivity and heavy metal were calculated for soil and corn samples collected from the Küçük Menderes Basin, Izmir, Turkey. Results have shown that our corn samples contain low radionuclide concentrations compared with literature and national limits. It seems that radionuclide especially ^{40}K, and heavy metal content of the soil and corn samples stems from phosphatic fertilizers used by farmers around the basin, as most of it is agricultural land (there is little industrial or household waste). Despite this, corn cultivation poses very little radionuclide or heavy metal risk to the basin. Such levels may offer reliable agro-businesses a point of reference. This study can tell us agricultural products of the basin are reliable for people.

Radioactivity research on soil-plant interactions also carries remarkable importance. Researchers need to conduct radiological monitoring alongside chemical, biological, and ecological soil analysis. The same goes for plant nutrition and health, as well as for fertilizer application. Researchers should also study and monitor more than one agricultural area for radioactivity levels by observing terrestrial radionuclides and analyzing TENORM data. Globally speaking, natural radionuclide content in the soil does not receive any external contributions. Then, regionally speaking, industrial activity does enrich local values. Uncontrolled industrial facilities and activates in Turkey are causing a rise in soil – and thus plant – pollution. Ecological pollution caused by terrestrial radionuclides and heavy elements must be monitored on a regular basis. In short, the findings in this case study could serve researchers and agriculturalists alike as a potential database.

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