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Determination of ^{210}Po and ^{210}Pb depositions in lichen and soil samples collected from Köprübaşı-Manisa, Turkey

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Abstract In this study, we aimed to determine the accumulations of ^{210}Po and ^{210}Pb in soil and lichen samples in Köprübaşı. The Köprübaşı district is home to the largest uranium deposits in Turkey. To date, there has been no study recorded in the literature related to ^{210}Po and ^{210}Pb depositions in lichens in Köprübaşı. Six different lichen species (*Cladonia convoluta*, *Parmelina tiliacea*, *Physcia stellaris*, *Pleurosticta acetabulum*, *Xanthoparmelia conspersa,* and *Xanthoria parietina*) as well as soil samples were collected from seven sampling locations around Köprübaşı. Lichens were used as biomonitors for ^{210}Po and ^{210}Pb deposition. The ^{210}Po and ^{210}Pb activity concentrations were measured in all the samples by alpha spectrometry. The activity concentrations in the lichen samples ranged from 64 to 577 Bq kg^{-1} with an average of 266 Bq kg^{-1} for ^{210}Po and from 78 to 565 Bq kg^{-1} with an average of 333 Bq kg^{-1} for ^{210}Pb. The activity ratios of ^{210}Po/^{210}Pb ranged from 0.80 to 1.99. In the lichen species, the mean ^{210}Po activity values varied from 154 Bq kg^{-1} in *Pleurosticta acetabulum* to 390 Bq kg^{-1} in *Xanthoparmelia conspersa.* The range of the mean ^{210}Pb activity was between 153 Bq kg^{-1} in *Cladonia convoluta* and 378 Bq kg^{-1} in *Parmelina tiliacea*. In the soil samples, ^{210}Po and ^{210}Pb activity concentrations were ranged from 14 to 1268 Bq kg^{-1} and from 19 to 1113 Bq kg^{-1}, respectively. While the values of ^{210}Po and ^{210}Pb measured in the lichen samples are comparable with those of the literature, the results of ^{210}Po and ^{210}Pb in the soil taken from the uranium mine are higher than the results of the literature studies.

Keywords ^{210}Po · ^{210}Pb · Manisa · Lichen

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1 Introduction

Lichens are symbiotic units formed from fungi and algae [1]. They have no roots or specialized structures for water and gas exchange. They need only a few nutrients and grow relatively slowly. They are perennial and live in various growth places (on soil, rocks, mosses, and trees) [2]. They can only live in places with clean air. They show a susceptibility to dirty air and are, therefore, a good indicator to imply whether the air of an area is clean or not [3]. Lichens have the ability to effectively accumulate a high level of different pollutants (SO_2, NO_2, ozone, heavy metals, and radionuclides) from the environment. They can be used as biomonitors of air pollution [4], because they highly depend on the atmospheric deposition for nutrients and easily collect pollutants in their thallus in line with atmospheric concentrations [4, 5]. Since the lichens absorb ^{210}Po from the air, they act as bioindicators for determining the amount of ^{210}Po in the atmosphere of that region.

^{210}Po is the decay product of ^{210}Pb in the ^{238}U decay series. It widely spreads in nature, the atmosphere, and oceans. ^{210}Po has short half-life ($t_{1/2}$, 138.4 days), but it stays in the atmosphere for a long time because of its parent radionuclides [^{210}Pb ($t_{1/2}$=22.3 years), ^{226}Ra ($t_{1/2}$= 1602 years], which have long half-lives. Therefore, the amount of ^{210}Po in nature depends largely on the amount of ^{210}Pb [6].

^{222}Rn emanation from the earth surface into the atmosphere is the main source of ^{210}Po. It travels back to the earth surface as attached to airborne particles [7]. Uranium mines are also sources [8]. Extra atmospheric ^{210}Po can originate from the external sources, such as volcanic emissions, inflow of the air, and anthropogenic emissions, e.g., emission from coal combustion, waste discharge from the gas, phosphate, and oil industries [7, 9].

^{210}Po decays directly to ^{206}Pb by emitting an alpha particle with 5.30 MeV energy [6, 7, 9]. Alpha particles are the most dangerous radiation type and are 400 times more radioactive than uranium. They have a low energy; therefore, they do not pass through a human skin, but easily permeate into the body from the respiratory tract, mouth or open wounds in the skin and pass through living cells [9]. If ^{210}Po is taken inside the body, large part of ingested ^{210}Po passes through the gastrointestinal tract within a few days. It is excreted with the feces. The retained ^{210}Po passes into the blood, it is stored by the soft tissue including the bone marrow. The biologic half-life of ^{210}Po is almost 50 days [10]. ^{210}Po and other radon products inhaled from the air can lead to lung cancer. Moreover, when ^{210}Po is ingested, it is hazardous to human health [9]. Radiation doses occurring in humans increase the risk of cancer. Very high radiation doses cause damage to the tissue and organs and overdoses can be fatal.

Studies on ^{210}Po in the environment are important as tracing the atmospheric emissions in populated areas is related to human health [9]. There have been several studies related to ^{210}Po and ^{210}Pb depositions using lichens [1, 6, 11–14]. However, no study has been performed on the lichens radioactivity in Köprübaşı-Manisa. In the present study, we determined ^{210}Po and ^{210}Pb activity concentrations in lichen and soil samples collected from the Köprübaşı district of Manisa. The determination of ^{210}Po and ^{210}Pb accumulations in the studied area is important in determining the environmental pollution and the radiation exposure of the inhabitants.

2 Materials and methods

2.1 Study area

Köprübaşı district is located 120 km northeast of Manisa in the Aegean region of Turkey. It is bordered by Gördes in the northwest, Demirci in the northeast, Gölmarmara in the west, Demirköprü Dam in the southeast, Salihli in the southwest, Kula and Alaşehir in the south, and Selendi in the east. Köprübaşı is located at 38°44′N latitude and 28°24′E longitude. It has a surface area of 447 km^2. The Dibek Mountains are in the southwest of the district, the Çanak Mountains in the northeast, and Kayran Mountains in the north [15]. The elevation of Köprübaşı is 250 m. It has a Mediterranean climate with hot and dry summers, and rainy and mild winters.

According to the General Directorate of Mineral Research and Exploration of Turkey (MTA) inventory of mining in the Aegean region, the Köprübaşı area contains marble, feldspar, phosphate, sulfur, titanium, and zeolite deposits [16]. There are also uranium deposits in fluvial sedimentary rocks. The Köprübaşı uranium deposit was discovered by MTA in 1961 [17]. It is the largest known uranium deposit in Turkey [17]. Apatite, biotite, feldspar, ilmenite-magnetite, muscovite, quartz, rutile, tourmaline, and zircon minerals are found in Köprübaşı uranium deposits [18].

In this work, lichen and soil samples were collected from seven sampling locations in Köprübaşı in July 2013. The sampling locations are shown in Fig. 1.

The lichen samples were collected from the surfaces of trees and then placed into the paper bags after wrapping in paper towels. The sampling locations, location number, date, type of substrate, altitude, and coordinate information determined by Garmin brand GPS devices were noted. Soil samples were also obtained at each of the locations.

2.2 Determination of ^{210}Po and ^{210}Pb activity concentrations

The inessential materials were cleaned from each sample in the laboratory. Samples were dried at room temperature and then grinded and sieved. One gram of sample was weighed and concentrated acids (HNO_3 and H_2O_2) were added, before leaving the samples overnight. The following day, the solution was heated on a hot plate and evaporated to dryness. Mixed acids (HNO_3 and HCl) were added to the dried residue. The solution was then evaporated to dryness again by heating on a hot plate. This process was repeated a total of four times. After evaporation, 0.5 M HCl acid was added to the dry residue. The solution was filtered with filter paper (particle retention 10–

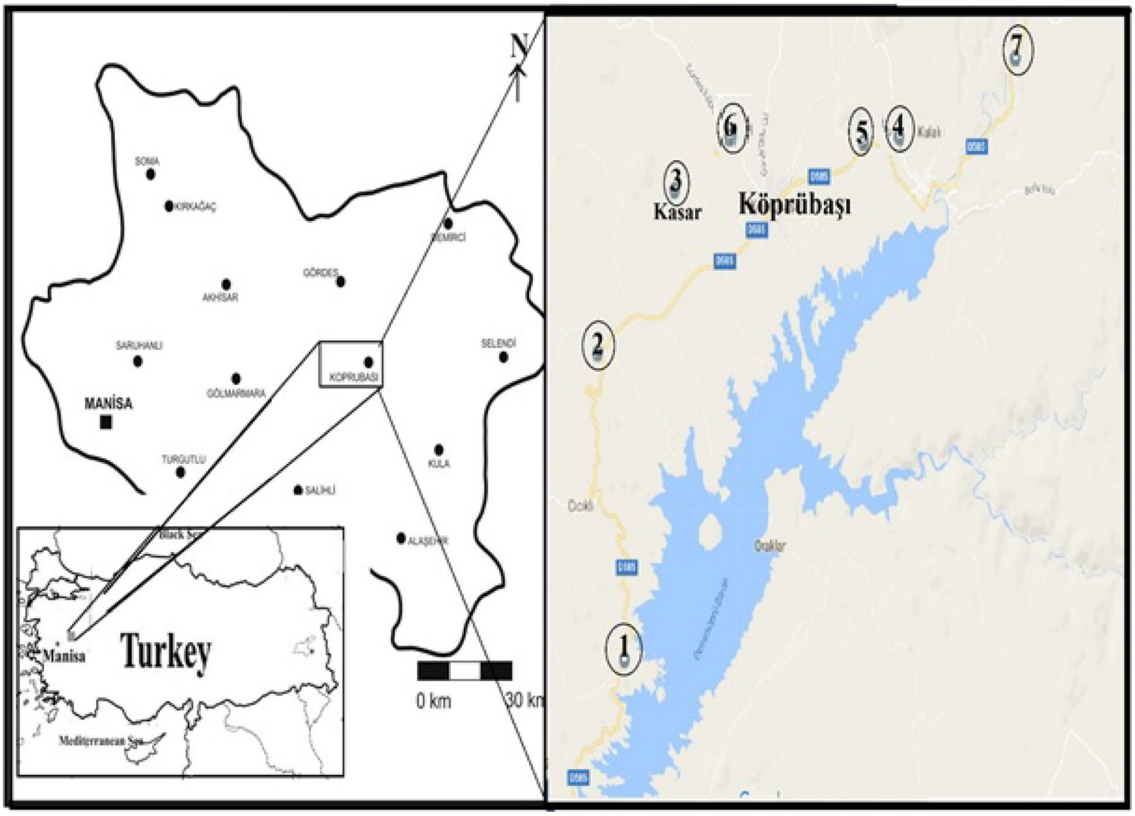

Fig. 1 (Color online) Map showing the sampling locations (1, 2, 3, 4, 5, 6 and 7) at Köprübaşı-Manisa: (1) Çarıklar village, (2) Kozakli village, (3) Kasar uranium deposit, (4) West of Borlu, (5) Northeast of Köprübaşı, (6) the Köprübaşı-Gordes road, and (7) the Salihli-Simav road

15 µm, 125 mm diameter, and 84 g m^{-2} weight). Ascorbic acid was added to the solution to reduce Fe^{3+}. A copper disc of diameter 2.5 cm was prepared. ^{210}Po was spontaneously accumulated onto the copper disc at 70 °C for 5 h.

The ^{210}Po accumulated onto the copper disc was counted for 5 h with an alpha spectrometer equipped with a PIPS detector placed in a vacuum chamber connected to a 1024 multichannel analyzer (Canberra). The energy resolution was≤20 keV with a detector source spacing equal to the detector diameter. The detector efficiency was≥25% of the detector source spacing of≤10 mm. The background was≤1 count/hour above 3 MeV. The system calibration was performed with an ^{241}Am point source.

The measurement of ^{210}Po was performed using the alpha particle emission peak with 5.30 MeV energy, using ^{209}Po as the internal tracer (National Institute of Standards & Technology, SRM 4326 consists of radioactive polonium-209 chloride and hydrochloric acid dissolved in 5 ml of distilled water. The solution mass was 5.160±0.003 g. It is enclosed in a flame sealed NIST borosilicate glass ampoule. The ^{209}Po massic activity of the solution was 85.42 Bq g^{-1}).

In this study, the chemical efficiency was calculated as 37.7% using the ^{209}Po standard. The total efficiency was found to be 102%. The ^{210}Po activity concentration for each sample was corrected for recovery using the total efficiency.

The ^{210}Pb activity measurement was performed indirectly from its measured product ^{210}Po activity after reaching radioactive equilibrium. The ^{210}Pb and ^{210}Po isotopes reached secular equilibrium at least 6 months after the first ^{210}Po electro-deposition. At this time, ^{210}Po grew from the ^{210}Pb of the sample. The ^{210}Po deposition in the lichen samples for the ^{210}Pb activity was collected on the cupper discs at 70 °C for 5 h and counted for 5 h by the alpha spectrometer. The ^{210}Pb activity concentration from the measured ^{210}Po activity in the analyzed samples was calculated by the Bateman equation [19]:

$$A_0(^{210}\mathrm{Pb}) = \frac{A_2(^{210}\mathrm{Po})}{1 - \mathrm{e}^{-\lambda(t_2 - t_1)}},$$

where A_0 (^{210}Pb) is the activity of a sample during the collection time, A_2 (^{210}Po) is the activity of ^{210}Po ingrown from ^{210}Pb after the second electro-deposition, t_1 is the time between the sample collection time and the first ^{210}Po activity measurement, t_2 is the time between the sample collection date and the second ^{210}Po activity measurement, and λ is the decay constant of ^{210}Po [19].

2.3 Determination of gamma radioactivity in soil samples

The soil samples collected from the seven sampling locations in Köprübaşı were milled and dried in an oven in the laboratory, before being sieved and weighed at 100 g in a polyethylene beaker. They were tightly closed and stored for as a minimum of 4 weeks to permit the ^{238}U and ^{232}Th to arrive at equilibrium with their decay products. The gamma measurements were performed by a gamma ray spectrometer using a 3×3 inch NaI(Tl) (ORTEC-905-4) detector. The system calibration was made with the standard samples (52% K, 625 ppm eU and 150 ppm eTh) under appropriate conditions. The best available resolution was < 7.5% for the gamma peak of ^{137}Cs (662 keV). The activity concentrations for ^{40}K, ^{238}U, and ^{232}Th were evaluated from the radioactive potassium peak (1.46 MeV), the ^{214}Bi peak (1.76 MeV), and the ^{208}Tl peak (2.61 MeV), respectively. All the samples were counted for 7200 s. The ^{40}K, ^{238}U and ^{232}Th activities were then calculated.

3 Results and discussion

3.1 Results of ^{210}Po and ^{210}Pb activity concentrations in samples

The 17 lichen samples of six different species (*Cladonia convoluta*, *Parmelina tiliacea*, *Physcia stellaris*, *Pleurosticta acetabulum*, *Xanthoparmelia conspersa,* and *Xanthoria parietina)* and seven soil samples were collected from seven sampling locations in Köprübaşı district. The lichen species are presented in Fig. 2. The results of the ^{210}Po and ^{210}Pb activity measured in the samples, according to sampling location, are presented in Table 1.

At location 1, according to Table 1, there were two different lichen species and the highest ^{210}Po and ^{210}Pb activities of 577 and 493 Bq kg^{-1}, respectively, were obtained in *Xanthoria parietina*. These values were the highest activities among all lichen samples. In location 2, while the highest value for ^{210}Po was obtained as 290 Bq kg^{-1} in *Xanthoparmelia conspersa*, the highest value for ^{210}Pb was calculated as 270 Bq kg^{-1} in *Physcia stellaris*. There were six different lichen species in location 3, where the Kasar uranium deposit is located. The highest activities for ^{210}Po and ^{210}Pb of 504 and 565 Bq kg^{-1}, respectively, were obtained for *Parmelina tiliacea.* In location 4, there was only one lichen species, namely *Xanthoria parietina.* In location 5, there were three different lichen types, with the highest obtained activities for ^{210}Po (171 Bq kg^{-1}) and ^{210}Pb (144 Bq kg^{-1}) in *Xanthoria parietina*. In location 6, the highest activities for ^{210}Po (176 Bq kg^{-1}) and ^{210}Pb (190 Bq kg^{-1}) were detected in *Parmelina tiliacea*. In location 7, there was only one lichen species. The activities of ^{210}Po and ^{210}Pb in *Xanthoria parietina* were 450 and 227 Bq kg^{-1}, respectively. The polonium accumulation is also affected by such factors as the age, health, and type of the lichen species, including their positions on trees, surface structure [20], altitudes where the lichens grow, and meteorological conditions (wind and rain). The mean annual rainfall of Köprübaşı is 575.8 mm and average annual temperatures range from 4.1 to 27.3 °C in 2013. *Xanthoria parietina* is the most common lichen species and was found at all locations except for location 2. It was assumed to be the most suitable bioindicator for pollution in the study area due to its high capture efficiency, geographical and climatic suitability, and common occurrence.

While the ^{210}Po activity levels in soil samples collected from six locations, except for location 3, varied between 14 and 53 Bq kg^{-1}, the ^{210}Pb activity levels ranged from 19 to 55 Bq kg^{-1}. It can be seen that the activity concentration in the samples in location 3 (1268 Bq kg^{-1} for ^{210}Po and 1113 Bq kg^{-1} for ^{210}Pb) were higher than in the samples from the other locations. Uranium mining had previous occurred in this area (location 3). In the other locations, ^{210}Po and ^{210}Pb concentrations in the soil samples were lower than those for lichen. This implies that lichens do not feed from the soil as they do not have roots and are affected by atmospheric fallouts.

The ^{210}Po and ^{210}Pb activities in the lichen and soil samples in this study were compared with those in the literature in Table 2. In the study, the mean ^{210}Po and ^{210}Pb activity levels in the lichen samples were similar to those of similar studies in the literature. The ^{210}Po/^{210}Pb ratio in the present study was found to be unity, implying the equilibrium between the ^{210}Po and ^{210}Pb radioisotopes. The ^{210}Po measured in lichens originates from ^{210}Pb, which is its parent in the uranium chain.

The mean ^{210}Po and ^{210}Pb activities according to the lichen species are shown in Fig. 3. The mean activity ratios of ^{210}Po/^{210}Pb are presented in Table 3.

The mean ^{210}Po and ^{210}Pb activities in lichen species ranged from 154 to 390 Bq kg^{-1} and from 153 to 378 Bq kg^{-1}, respectively. While the highest mean activity for ^{210}Po was detected in *Xanthoparmelia conspersa,* the lowest mean activity was seen in *Pleurosticta acetabulum*. For ^{210}Pb, while the highest mean activity was seen in *Parmelina tiliacea*, the lowest activity was found in *Cladonia convolute* (Table 3).

The mean activity ratios of ^{210}Po/^{210}Pb in the lichen species ranged from 0.85 to 1.52. The activity ratio of

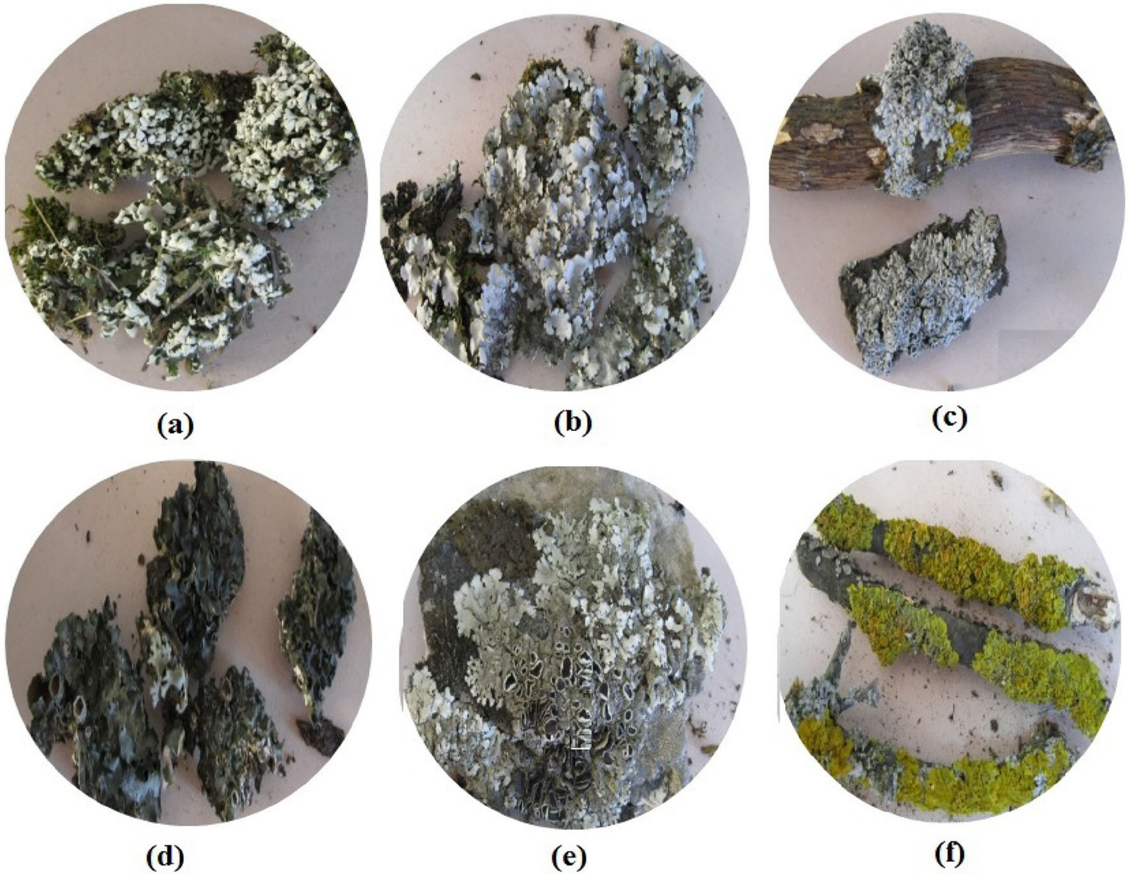

Fig. 2 (Color online)Lichen species collected from the Köprübaşı district: **a** *Cladonia convoluta*, **b** *Parmelina tiliacea*, **c** *Physcia stellaris*, **d** *Pleurosticta acetabulum*, **e** *Xanthoparmelia conspersa*, and **f** *Xanthoria parietina*

Table 1 ^{210}Po and ^{210}Pb activity concentrations of the samples according to sampling location (Bq kg^{-1})

Samples (*n*: sample number)	Location 1		Location 2		Location 3		Location 4		Location 5		Location 6		Location 7	
	^{210}Po	^{210}Pb	^{210}Po	^{210}Pb	^{210}Po	^{210}Pb	^{210}Po	^{210}Pb	^{210}Po	^{210}Pb	^{210}Po	^{210}Pb	^{210}Po	^{210}Pb
Lichen species														
Cladonia convoluta (*n*: 2)	138	105	–	–	328	201	–	–	–	–	–	–	–	–
Parmelina tiliacea (*n*: 2)	–	–	–	–	504	565	–	–	–	–	176	190	–	–
Physcia stellaris (*n*: 3)	–	–	222	270	331	378	–	–	66	79	–	–	–	–
Pleurosticta acetabulum (*n*: 2)	–	–	–	–	194	215	–	–	114	143	–	–	–	–
Xanthoparmelia conspersa (*n*: 2)	–	–	290	256	489	457	–	–	–	–	–	–	–	–
Xanthoria parietina (*n*: 6)	577	493	–	–	245	267	64	78	171	144	148	154	450	227
Soil samples (*n*: 7)	45	51	53	55	1268	1113	24	40	14	22	19	24	21	19

$^{210}Po/^{210}Pb$ was unity in *Xanthoparmelia conspersa.* This demonstrates the equilibrium between the ^{210}Po and ^{210}Pb radioisotopes. In three lichen species (*Parmelina tiliacea, Physcia stellaris,* and *Pleurosticta acetabulum),* the ^{210}Pb deposition was greater than the ^{210}Po deposition. This disequilibrium indicated the presence of ^{210}Pb due to the atmospheric deposition in the lichen species. Since the ground surface is the main source of airborne ^{210}Pb, the air concentrations of ^{210}Pb show the local, geological, and global climatological background of the areas observed

Table 2 ^{210}Po and ^{210}Pb activity results (Bq kg^{-1}) and ^{210}Po/^{210}Pb ratios in the lichen and soil samples in the literature

Study area	Lichen			Soil			References
	^{210}Po	^{210}Pb	^{210}Po/^{210}Pb	^{210}Po	^{210}Pb	^{210}Po/^{210}Pb	
Norway	70–212 (140.5)	–	–	–	–	–	[13]
India	–	–	–	6.6–35.3 (19.3)	11.7–85.7 (38.5)	0.1–1.5 (0.45)	[21]
Norway	39–137.5 (88.3)	150–188 (169)	0.3–0.7 (0.5)	36.9–42.87 (39.8)	39.4–46.05 (42.7)	0.86–1 (0.9)	[12]
Hungary	–	–	–	37–184 (85.3)	–	–	[7]
Turkey-Emendere	185	–	–	66	–	–	[14]
Turkey-Çan	98.4–206.1 (161.6)	153.6–326.4 (259.1)	0.5–0.78 (0.6)	42.8–135.7 (79.9)	30.8–177.6 (91.5)	0.62–1.86 (0.87)	[11]
Western Turkey	151–593 (378)	97–360 (233)	–	–	–	–	[22]
Western Turkey	117–569 (365)	84–291 (206)	1.39–2.33 (1.7)	–	–	–	[1]
Köprübaşı-Turkey	154–390 (267)	153–378 (256)	0.79–1.98 (1.04)	14–1268 (29.3)	19–1113 (35.2)	0.74–1.13 (0.87)	This study

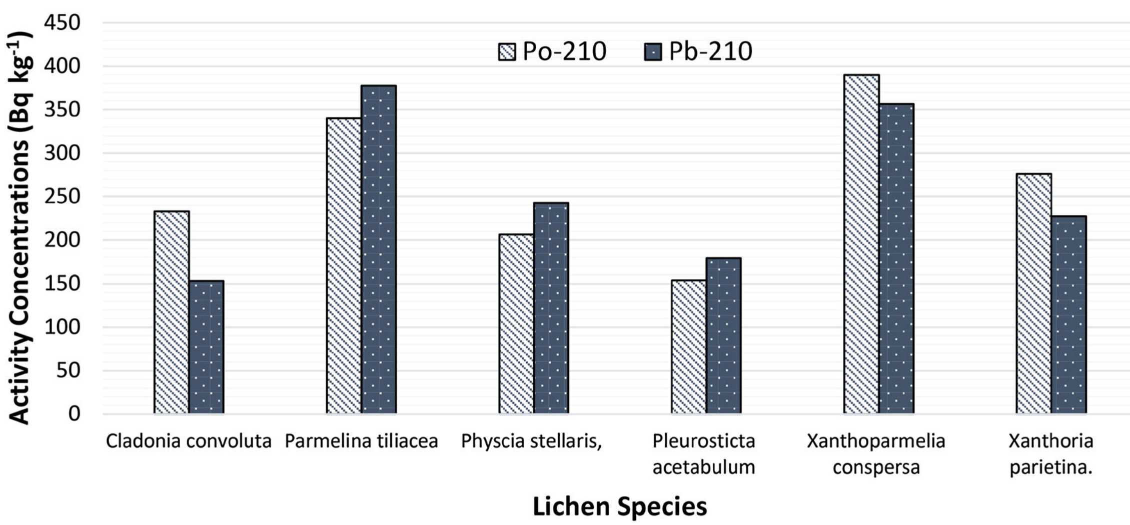

Fig. 3 Mean ^{210}Po and ^{210}Pb activity in the lichen species at Köprübaşı

[23]. In the *Cladonia convoluta* and *Xanthoria parietina* lichen species, the ^{210}Po deposition was higher than the ^{210}Pb deposition (Table 3). The activity ratio of ^{210}Po/^{210}Pb in the *Cladonia convolute* lichen species is higher than the other results. This lichen species was collected at two locations (locations 1 and 3). When the activity ratios for this species were calculated according to the sampling locations and were 1.3 and 1.63 in locations 1 and 3 (Kasar uranium deposit), respectively. According to the results, the ^{210}Po activity concentrations were higher than the ^{210}Pb activity concentrations. This result shows that the polonium was a contribution not only from the predominant ^{210}Pb but also from the environment. The Kasar uranium deposit is located in location 3 and it can be concluded that the uranium mine affected the polonium activity. The polonium accumulation is affected by the deposits of marble, feldspar, phosphate, sulfur, titanium, and zeolite. This is because the level of ^{210}Po in the atmosphere of tungsten, molybdenum, iron, and phosphate rocks is higher [24, 25]. The Köprübaşı uranium deposits are found in apatite,

Table 3 Mean ^{210}Po and ^{210}Pb activities and the activity ratios of $^{210}Po/^{210}Pb$ of the lichen species

Lichen species	^{210}Po (Bq kg^{-1})	^{210}Pb (Bq kg^{-1})	The activity ratio of $^{210}Po/^{210}Pb$
Cladonia convoluta (*n*=2)	233	153	1.52
Parmelina tiliacea (*n*=2)	340	378	0.90
Physcia stellaris (*n*=3)	206	242	0.85
Pleurosticta acetabulum (*n*=2)	154	179	0.86
Xanthoparmelia conspersa (*n*=2)	390	356	1.09
Xanthoria parietina (*n*=6)	276	227	1.21
Min.	154	153	0.85
Max.	390	378	1.52
Mean	267	256	1.04

biotite, feldspar, ilmenite-magnetite, muscovite, quartz, rutile, tourmaline, and zircon minerals.

A correlation graphic of ^{210}Po activity versus ^{210}Pb activity in the lichen samples is given in Fig. 4. It can be seen that there was a positive correlation of 0.91 between the two radionuclides, with an R^2 value of 0.78.

3.2 Results of gamma radioactivity in soil samples

The ^{40}K, ^{238}U, and ^{232}Th activities were measured by gamma spectrometry and the obtained results are given in Table 4.

Standard error values for the ^{40}K, ^{238}U, and ^{232}Th activities were calculated separately and were 129, 161, and 8, respectively. These are shown in Fig. 5.

In the soil samples, the ^{40}K activity ranged between 250.25 and 1064.60 Bq kg^{-1} with an average value of 506.19 Bq kg^{-1}. The highest concentration of ^{40}K was measured in the sample collected from location 5 (Table 4 and Fig. 5). The world average for ^{40}K is accepted as 400 Bq kg^{-1} [26], and therefore, 71.5% of the results in this study exceeded the world average.

Table 4 ^{40}K, ^{238}U, and ^{232}Th activity concentrations of soil samples in the Köprübaşı district (Bq kg^{-1})

Soil samples	^{40}K	^{238}U	^{232}Th
1	601.91	53.86	16.41
2	250.25	52.84	34.61
3[a]	–	1267.8	80.57
4	703.81	53.77	32.14
5	1064.60	42.60	27.19
6	569.92	52.21	33.26
7	352.80	41.73	14.61
Min.	250.25	41.73	14.61
Max.	1064.60	1267.8	80.57
Mean	506.19	49.5	39.92

[a] Kasar uranium deposit

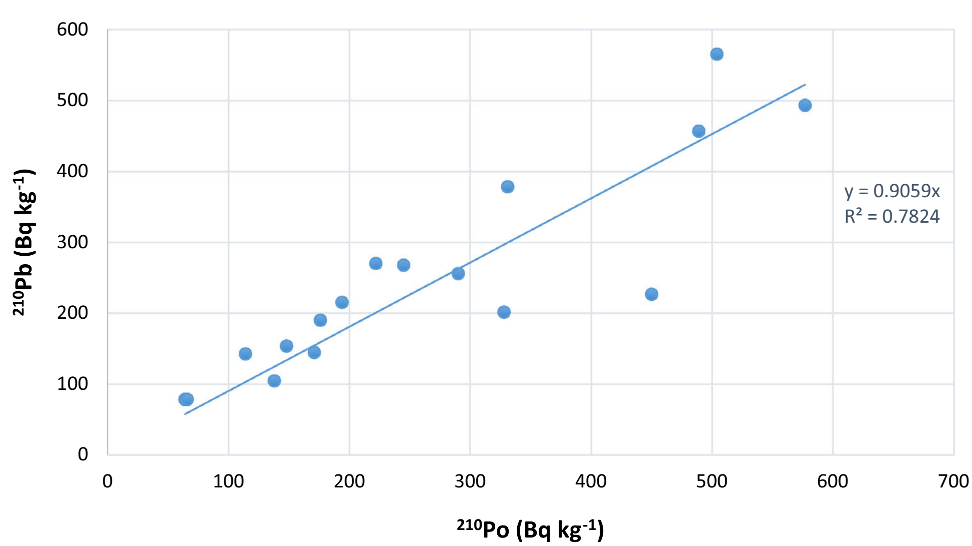

Fig. 4 Relationship between the ^{210}Po and ^{210}Pb activity in the lichen samples

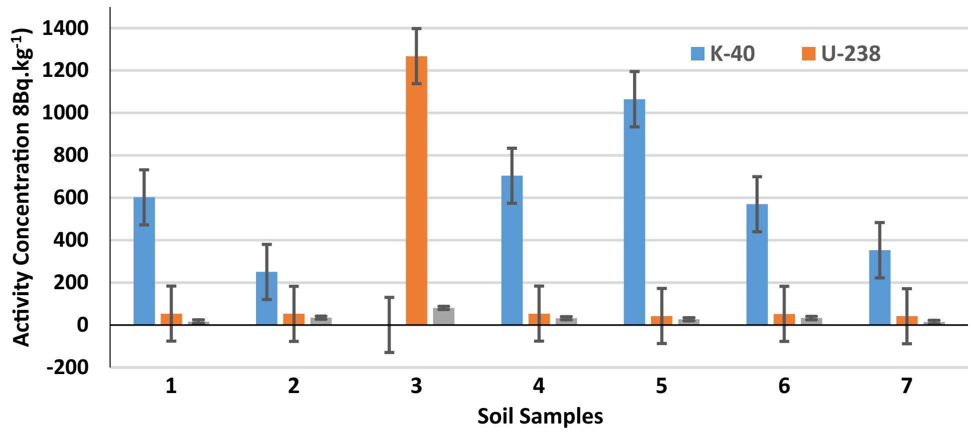

Fig. 5 (Color online)^{40}K, ^{238}U, and ^{232}Th activities in the soil samples

The ^{238}U activity in the soil samples ranged from 41.73 to 1267.8 Bq kg^{-1}, with an average value of 49.5 Bq kg^{-1}, except at location 3. The ^{238}U activity concentration in all soil samples was higher than the world average for ^{238}U which is accepted as 35 Bq kg^{-1} [26]. In particular, the ^{238}U activity concentration in the soil sample taken from the Kasar uranium mine (location 3) is very high (approximately 36 times the world average).

The ^{232}Th activity varied from 14.61 to 111.92 Bq kg^{-1} with a mean value of 39.92 Bq kg^{-1}. The results of two samples (location 2 and location 3) were lower than the world average of 30 Bq kg^{-1} [26]. The mean of the ^{40}K, ^{238}U, and ^{232}Th activities in this study was exceeded the accepted values (400, 35, and 30 Bq kg^{-1}, respectively).

In the soil samples, the correlation between the ^{238}U activity concentration measured by gamma spectrometry and ^{210}Po activity concentration measured by alpha spectrometry is demonstrated in Fig. 6. It can be seen that the correlation between the ^{238}U and ^{210}Po activity is a positive (0.75) with an R^2 value of 0.998.

4 Conclusion

In this study, the ^{210}Po and ^{210}Pb activities in six different lichen species were measured by alpha spectrometry. The most common of the lichen species was *Xanthoria parietina* in the Köprübaşı district. The highest activities for ^{210}Po (577 Bq kg^{-1}) and ^{210}Pb (565 Bq kg^{-1}) in the lichen samples were detected in *Xanthoria parietina* and *Parmelina tiliacea*, respectively.

The highest mean activities of ^{210}Po and ^{210}Pb were detected in *Xanthoparmelia conspersa* and in *Parmelina tiliacea*, respectively. The lowest mean activities were seen in *Pleurosticta acetabulum* and *Cladonia convolute* for ^{210}Po and ^{210}Pb, respectively. The age, health, and locations of the lichens differed, and therefore, these factors can cause the accumulation of radionuclides in different proportions in the same species.

According to the lichen species, the activity ratio of ^{210}Po/^{210}Pb was unity in *Xanthoparmelia conspersa,* demonstrating the equilibrium between the ^{210}Po and ^{210}Pb

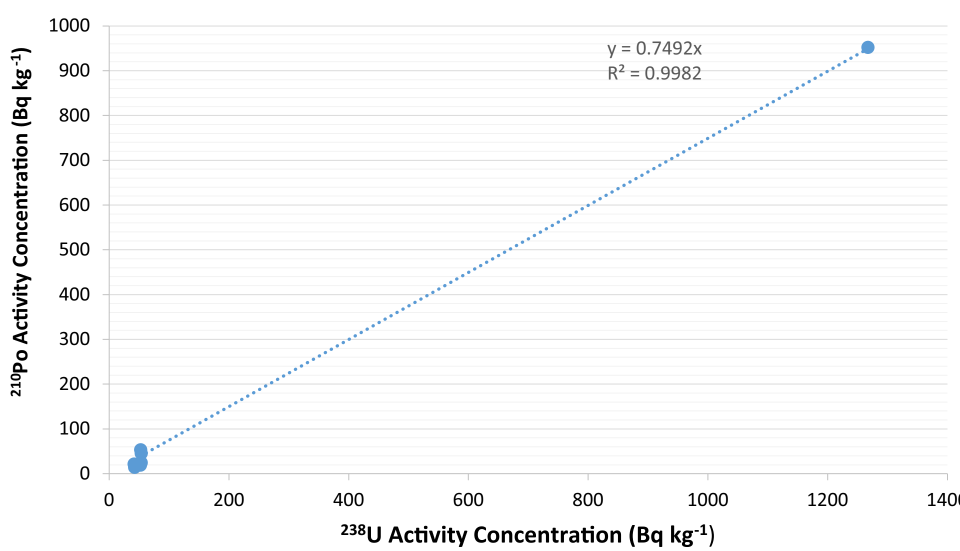

Fig. 6 Correlation between the ^{238}U activity and ^{210}Po activity concentrations in the soil samples

radioisotopes. However, this ratio in the other lichen species is varied from 0.85 to 1.52. In the lichen samples, there was a positive correlation of 0.91 between the ^{210}Po and ^{210}Pb activity with an R^2 value of 0.78. In addition, in the soil samples, there is a positive relation between the ^{238}U activity measured by gamma spectrometry and ^{210}Po activity measured by alpha spectrometry with an R^2 value of 0.998.

In this study, the ^{210}Po activity concentrations in the air using lichens were studied to investigate the dose limits affecting the human health of those living in this area. The ^{210}Po and ^{210}Pb levels of this area were determined and the obtained data important, because no such study has been performed in this region before. The results of this study can be used as the basic data in future studies, e.g., production of distribution maps.

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