Journal of Environmental Radioactivity 102 (2011) 535–542

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

journal homepage: www.elsevier.com/locate/jenvrad

Biomonitoring of ^{210}Po and ^{210}Pb using lichens and mosses around coal-fired power plants in Western Turkey

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ARTICLE INFO

Article history:
Received 28 June 2010
Received in revised form
31 January 2011
Accepted 4 February 2011
Available online 31 March 2011

Keywords:
Lichen
Moss
Biomonitors
Atmospheric deposition

ABSTRACT

Mosses and lichens are useful biological indicators of environmental contamination for a variety of metals and radionuclides of both natural and artificial origin. These plants lack a well-developed root system and rely largely on atmospheric deposition for nourishment. Therefore in the study, different lichens (*Cladonia convoluta*, *Cladonia foliacea*) and mosses (*Homalothecium sericeum*, *Hypnum lacunosum*, *Hypnum cupressiforme*, *Tortella tortuosa*, *Didymodon acutus*, *Syntrichia ruralis*, *Syntrichia intermedia*, *Pterogonium graciale*, *Isothecium alopecuroides*, *Pleurochatae squarrosa*) were collected around the Yatağan (Muğla), Soma (Manisa), Seyitömer – Tunçbilek (Kütahya) coal-fired power plants and investigated for potential use as biomonitors for ^{210}Po and ^{210}Pb deposition. While the activity concentrations of ^{210}Po and ^{210}Pb in lichens are in the ranges of 151 ± 7–593 ± 21 and 97 ± 5–364 ± 13 Bq kg^{-1}, for mosses the ranges for ^{210}Po and ^{210}Pb are 124 ± 5–1125 ± 38 and 113 ± 4–490 ± 17 Bq kg^{-1}, respectively. In the study, the moss samples were observed to accumulate more ^{210}Po and ^{210}Pb compared to lichens. While the most suitable biomonitor was a moss species (*H. lacunosum*) for Yatağan (Muğla), it was another moss species (*S. intermedia*) for Soma (Manisa) and Seyitömer – Tunçbilek (Kütahya) sites. ^{210}Po concentrations were found higher than ^{210}Pb concentrations at the all sampling stations.

1. Introduction

Lichens and mosses have been widely used as biomonitors for assessing the atmospheric deposition of heavy metals and radionuclides. Due to the lack of root system, they depend on surface absorption of nutrients and accumulate fallout radionuclides from atmosphere. Therefore, they are often used for biomonitoring pollution. In these plants, the accumulation degree is much higher than in vascular plants growing in the same habitats. Some species of lichen and moss have been widely used in nationwide surveys (Bargagli et al., 1995; Berg et al., 1995a; Figueira et al., 2002). The morphology of lichens and mosses does not vary with seasons. Thus, lichen and moss species retain and accumulate pollutants deposited from the atmosphere throughout the year (Sloof, 1993; Szczepaniak and Biziuk, 2003). Therefore, a large number of studies have used these organisms for monitoring regional patterns of elemental deposition from the atmosphere (Berg et al., 1995b; Fernandez et al., 2000; Figueira et al., 2002; Kirchner and Daillant, 2002; Real et al., 2003).

^{210}Po and ^{210}Pb are products of the ^{238}U decay series and are released into the atmosphere via the decay of ^{222}Rn. These radionuclides can also build up artificially in the environment as a result of man's activities such as fossil fuel burning power plant, fertilizer industries and exhaust gasses of traffic. However, exhaust gasses of traffic are similar from year to year, therefore do not contribute to a change in the annual deposition (Beks et al., 1998). ^{210}Pb and ^{210}Po return to the earth as dry fallout or washed out in rain. Especially, the coal-fired power plants are one of the major sources of increased natural radioactivity in the atmosphere. Coal contains natural radionuclides and their daughter products. In the process of combustion of coal, the natural radionuclides are released into the atmosphere. Most of the radionuclides accumulate in the ash. Depending on the emission control system of the chimney, some small proportion of the ash, called the fly ash, and chimney gases are released into the atmosphere. The amount of the natural radioactivity around the power plant depends on several factors such as the ash content of the coal, the electrostatic filter efficiency, meteorological conditions, etc (Delfanti et al., 1999). Baxter (1993) stated that the generation of one gigawatt-electric (GW_e) of coal-fired electricity results in the environmental release in fly ash and

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doi:10.1016/j.jenvrad.2011.02.005

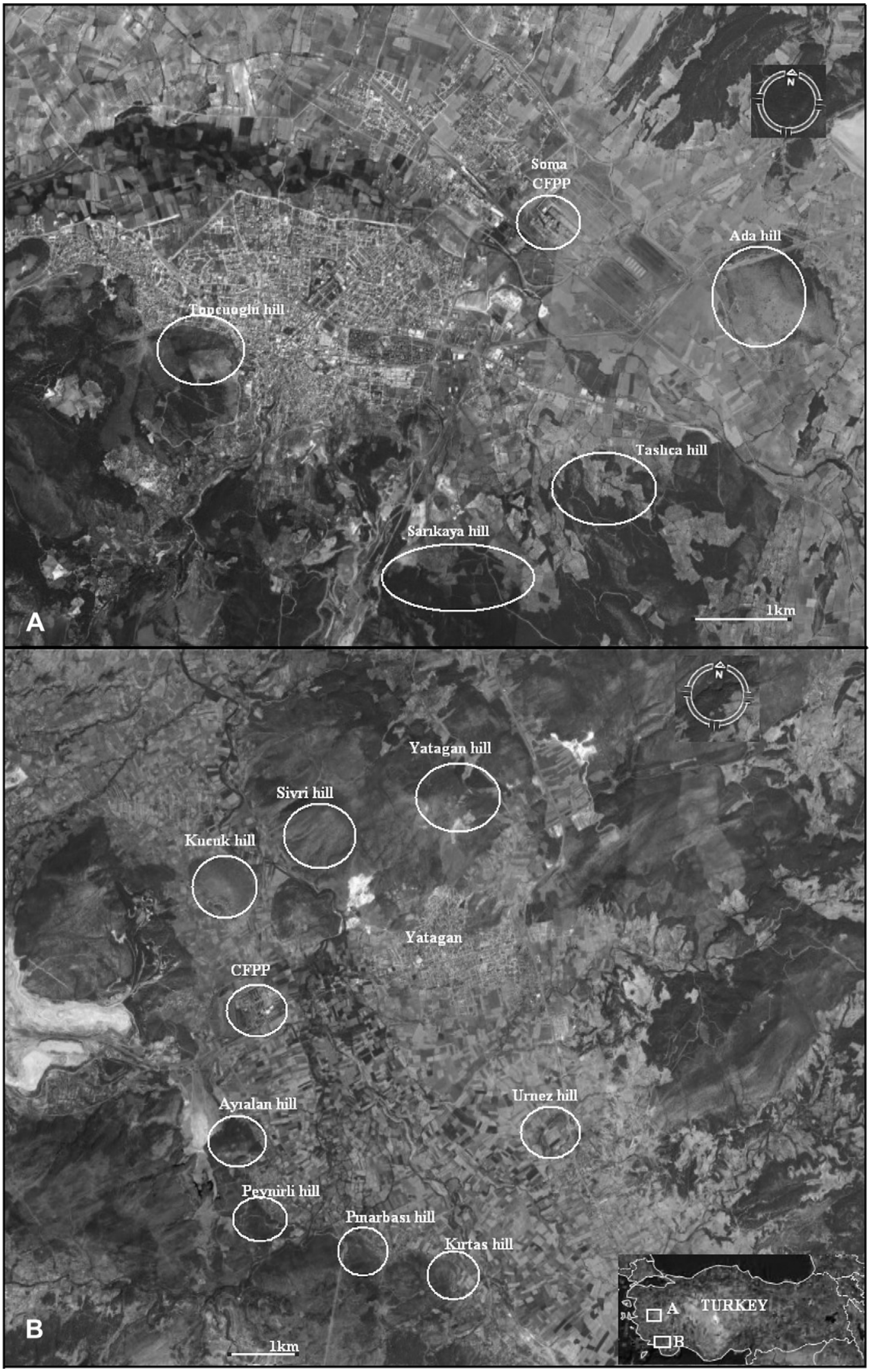

Fig. 1. General view of Soma (A) and Yatagan (B) study sites (from google earth).

off-gases of around 10^9–10^{11} Bq per year of both ^{220}Rn and ^{222}Rn and 10^8–10^{10} Bq y^{-1} each of ^{210}Pb, ^{210}Po, ^{226}Ra, ^{228}Ra, ^{232}Th and ^{238}U. In the same study Baxter also indicates that the natural radioactivity in the fly ash waste product is concentrated by volatilization and sorption processes relative to the original coal burned. This effect is most commonly associated with lead and polonium isotopes (metallic boiling points of 1749 °C and 962 °C, respectively). The average activity concentrations of ^{210}Pb and ^{210}Po in coal are 20, 20 whereas in fly ash 930,1700 Bq kg^{-1}, respectively (UNSCEAR, 1993).

There are several studies in which coal-fired power plants influence on the levels of natural radioactivity in the surrounding areas (Yener and Uysal, 1996; Ayçik and Ercan, 1997; Delfanti et al., 1999; Papp et al., 2002; Uğur et al., 2003; Krmar et al., 2009). Lichens and mosses have high interception potentials for aerosols in precipitation and therefore contain significantly higher ^{210}Po and ^{210}Pb concentrations than vascular plants and fungi (Uğur et al., 2003; Skuterud et al., 2005).

The objectives of this study are to (i) investigate on the effect of coal-fired power plants on radioactive pollution from uranium-series radionuclides, (ii) determine of ^{210}Pb and ^{210}Po concentrations in relation to different species of lichens and mosses and (iii) select the most suitable biomonitor for the region under investigation.

2. Materials and methods

2.1. The study sites

The study was realized around four plants namely Yatağan in Muğla province, Soma in Manisa province, Seyitömer and Tunçbilek in Kütahya province, Western Turkey. Sampling sites were selected in fields around coal ash areas and coal-fired power plants. Samples of the lichens and mosses were collected from 2003 to 2004 around the plants.

Yatağan (Muğla) sampling region is located in southwest of Turkey. Its area is 1524 km^2 and its population is 44,692. Yatağan (Muğla) has typical Mediterranean climate. This climate is characterized by hot, dry summers and cool, wet winters. Vegetation in the region includes mixed oak woods and Mediterranean marquis. According to the data which is given by Turkish State Meteorological Service, prevailing winds directions are south eastern, north eastern and south western. The mean annual rainfall of Yatağan region is 884.4 mm in 2003 and 643.8 mm in 2004 (http://www.dmi.gov.tr/veridegerlendirme/yillik-toplam-yagis-verileri.aspx). In Yatağan, there are three major uraniferous coal-fired power plants (CPP) namely, Yatağan CPP in operation since 1982, Yeniköy CPP, since 1988 and Kemerköy CPP, since 1994. Yatağan plant has three units producing 210 MW_e each, the other two plants have only two units of similar power. The Yatağan power plant in the study region is situated about 3 km from populated area. Eight hills around Yatağan coal-fired power plant were selected as study sites. Mosses and lichens were collected from Yatağan, Sivri, Küçük, Ayıalan, Peynirli, Pınarbaşı, Kırtaş and Ürnez hills indicated in Fig. 1. The samples were taken from different eight hills in the study site at the intersections of grids with various spacing depending on the total area of the hills to be sampled and topographic variability. At each sampling site, the area from which the moss and lichen samples were collected was no bigger than 50 × 50 m^2, and no smaller than 20 × 20 m^2. Subsamples were collected at each site, as recommended by Uğur et al. (2003). The topographic data for Yatağan site are shown in Table 1.

Soma is a town and a district of Manisa Province in western region of Turkey. Its area is about 826 km^2. The directions of prevailing winds are northern, western and north western in Soma region. The mean annual rainfall of Soma is 585.7 mm in 2003 and 471.6 mm in 2004 (http://www.dmi.gov.tr/veridegerlendirme/yillik-toplam-yagis-verileri.aspx). This region has also a major coal mining district for centuries, highly populated areas (89,038 inhabitants), large industry and intensive agriculture areas. Generally, its industry is concentrated on coal mining. The plant situated in Soma consists of two units producing 2 × 22 MW_e and 6 × 165 MW_e. It burns 734.5 tons coal per hour and emits 3.76 tons fly ash per hour. Four hills around Soma (Manisa) coal-fired power plant were selected as study sites. The samples were collected from Ada, Topçuoğlu, Sarıkaya and Taşlıca hills indicated in Fig. 1. The samples were taken from a 50 × 50 m^2 area at each location and were brought to laboratory in paper bags. The topographic data for Soma site are shown in Table 1.

Seyitömer and Tunçbilek (Kütahya) are in the north western part of Turkey. They have a low population density. The weather in the regions is occasionally rainy and snowy during the winter, and hot and dry during the summer. While prevailing winds directions are southern, south eastern and north western in Seyitömer region, the directions are southern, south western and northern in Tunçbilek region. The mean annual rainfall of Seyitömer and Tunçbilek regions is 585.7 mm in 2003 and 471.6 mm in 2004 (http://www.dmi.gov.tr/veridegerlendirme/yillik-toplam-yagis-verileri.aspx). Seyitömer and Tunçbilek (Kütahya) produce about 4 × 150 MW and 250 MW of electrical energy at full load, and consume coal about 466 tons per hour and 255 tons per hour, respectively. Besides, the total particle emission of power plants is 6.96 tons per hour. Four hills around Seyitömer and Tunçbilek (Kütahya) coal-fired power plants were selected as study sites. The samples were collected from Kayıncak, Kaklık, Kocadüz and Bozcahöyük hills indicated in Fig. 2. The samples were taken from a 50 × 50 m^2 area at each location and were brought to laboratory in paper bags. The topographic data for Seyitömer and Tunçbilek sites are shown in Table 1.

Table 1
Topographic data of study sites.

Location	Sampling Site	Distance from CFPP (km)	Altitude (m)	Grid (m^2)	Slope
Yatağan	Yatağan Hill	4.5	580–710	50 × 50	%20–60
	Sivri Hill	2.8	350–500	50 × 50	%20–60
	Küçük Hill	1.6	364–384	50 × 50	%05–30
	Ayıalan Hill	2.2	432–483	30 × 30	%50–65
	Peynirli Hill	3.0	379–391	20 × 20	%60
	Pınarbaşı Hill	5.6	396–388	25 × 25	%45–65
	Kırtaş Hill	7.0	390–410	50 × 50	%5–20
	Ürnez Hill	7.0	356–394	20 × 20	%10–20
Soma	Ada Hill	2.5	194–250	50 × 50	%50–70
	Topçuoğlu Hill	1.1	241–308	50 × 50	%60–70
	Sarıkaya Hill	4.5	360–421	50 × 50	%30
	Taşlıca Hill	3.8	278–346	50 × 50	%60
Tunçbilek	Kayıncak Hill	2.6	797–827	50 × 50	%30
	Kaklık Hill	3.2	761–811	50 × 50	%25
Seyitömer	Kocadüz Hill	1.0	1133–1159	50 × 50	%50–60
	Bozcahöyük Hill	1.6	1126–1232	50 × 50	%40

In the study, lichen (*Cladonia convoluta-Cc*, *Cladonia foliacea-Cf*) and moss species (*Homalothecium sericeum-Hs*, *H. lacunosum-Hl*, *Hypnum cupressiforme-Hc*, *Tortella tortuosa-Tt*, *Didymodon acutus-Da*, *Syntrichia ruralis-Sr*, *Syntrichia intermedia-Si*, *Pterogonium graciale-Pg*, *Isothecium alopecuroides-Ia*, *Pleurochatae squarrosa-Ps*) were studied for potential use as bioindicators of ^{210}Po and ^{210}Pb radioactive contaminations around the coal-fired power plants.

2.2. The radiochemical analysis and measurements

In the laboratory, the samples of lichen and moss were carefully cleaned to remove as much extraneous material as possible and then dried to constant weight at 85 °C for 48 h and their weights were determined. After standard addition of polonium-208 tracer, 1.5 g of each sample was completely dissolved with concentrated HNO_3 under heating at 55 °C on a hot plate and evaporated to dryness three times. Concentrated H_2O_2 was also used in the dissolving process. After this step, concentrated HCl was added and evaporated to dryness three times (HNO_3:H_2O_2:HCl = 30:1:30 mL). Polonium was spontaneously plated onto copper discs in 0.5 M HCl in the presence of ascorbic acid to reduce of Fe^{+3} to Fe^{+2} (Flynn, 1968). Measurements of ^{210}Po were made through its 5.30 MeV alpha particle emission, using ^{208}Po (95 ± 1.3 mBq g^{-1}) as the internal tracer (AEA Technology, 5.38 ± 0.02 g of 2 M nitric acid in a flame sealed break neck glass ampoule, ^{208}Po alpha activity concentration 2.25 ± 0.03 KBq g^{-1}). Lichen and moss samples analyzed in previous work were found to contain high Fe concentrations (Uğur et al., 2003, 2004). Hence the deposition of ^{210}Po was examined for different amounts of ascorbic acid to obtain the maximum recovery. Optimum deposition time was obtained as 6 h. The chemical efficiency for each measurement at optimum conditions was obtained to be between 75 and 95%. ^{210}Po activity was corrected for recovery by comparing with the measured activity of the ^{208}Po yield tracer and for radioactive decay from the time of sampling. The alpha activity measurements of polonium isotopes plated on copper discs were performed with silicon surface-barrier detector, Tennelec − 400 mm^2, 300 μm depletion depth, for which the efficiency is 29% using ^{226}Ra source. Concentrations of ^{210}Po in samples were found to be much above the detection limits (0.0003 Bq). Counting period was adjusted to obtain relative standard errors of approximately 5%. ^{210}Pb concentrations were determined from ^{210}Po activities measured after attaining the radioactive equilibrium. Well known Bateman equations were used to obtain ^{210}Pb activity from measured ^{210}Po activity. So, the second deposition provided information on the ^{210}Pb content of the samples and hence on the extent to which the initial ^{210}Po was supported by its grand parent.

3. Results and discussion

The activity concentrations of ^{210}Po and ^{210}Pb in lichen samples were found to vary between 151 ± 7–593 ± 21 and 97 ± 5–360 ± 13 Bq kg^{-1}, respectively. The range of activity values in moss samples

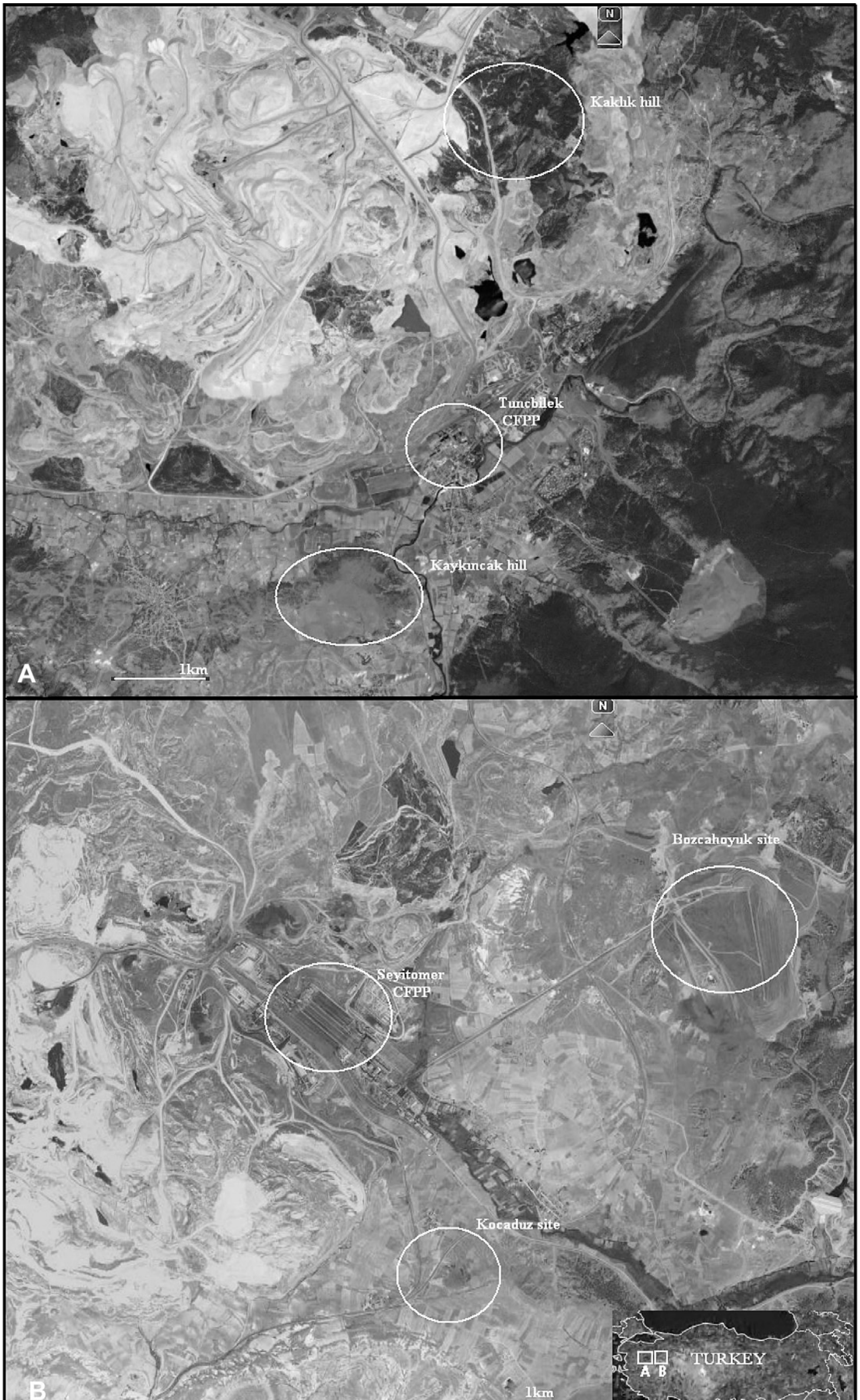

Fig. 2. General view of Tunçbilek (A) and Seyitömer (B) sites (from Google earth).

Table 2
Mean, minimum (Min) and maximum (Max) of ^{210}Po and ^{210}Pb (Bq kg^{-1}) in lichen and moss species collected in Yatağan (Muğla). (n = number of samples).

		^{210}Po (Bq kg^{-1})	^{210}Pb (Bq kg^{-1})
Cladonia convoluta ($n = 52$)	Mean	400	246
	Min.	151	111
	Max.	593	360
Tortella tortuosa ($n = 28$)	Mean	500	384
	Min.	310	253
	Max.	785	589
Homalothecium sericeum ($n = 27$)	Mean	382	307
	Min.	225	158
	Max.	660	490
Pterogonium graciale ($n = 11$)	Mean	364	243
	Min.	124	108
	Max.	732	389
Isothecium alopecuroides ($n = 3$)	Mean	465	306
	Min.	375	280
	Max.	540	388
Didymodon acutus ($n = 3$)	Mean	455	333
	Min.	400	280
	Max.	510	386
Hypnum lacunosum ($n = 3$)	Mean	506	387
	Min.	493	355
	Max.	518	419
Hypnum cupressiforme ($n = 3$)	Mean	286	208
	Min.	230	159
	Max.	342	257

were between 124 ± 5 and 1125 ± 38 Bq kg^{-1} for ^{210}Po, 94 ± 4 and 724 ± 25 Bq kg^{-1} for ^{210}Pb. The results of the analysis of samples collected in Yatağan (Muğla), Soma (Manisa) and Seyitömer – Tunçbilek (Kütahya) are given in Tables 2–4, respectively. It is seen in these Tables ^{210}Po and ^{210}Pb concentrations are different for each lichen and moss.

The differences observed in ^{210}Po and ^{210}Pb concentrations in lichen and moss samples could be linked to the differences in accumulation properties of species. Moreover, the type of vegetation cover the sampling points is an important difference. Some lichen and moss species that grow in lower parts of tree trunks are protected from direct radioactive deposition. *P. graciale* and *I. alopecuroides* are found growing on bases and trunks of holm oak (*Quercus ilex*) and *C. foliacea* is available on cracked rocks. *D. acutus* is growing on rocks background. *H. lacunosum* and *S. ruralis* grow on soil and rocks. *P. squarrosa* usually found in unshaded habitats.The lowest activity concentrations of ^{210}Po and ^{210}Pb were found in *H. cupressiforme* which collected under trees for Yatağan.

Table 3
Mean, minimum (Min) and maximum (Max) of ^{210}Po and ^{210}Pb (Bq kg^{-1}) in lichen and moss species collected in Soma (Manisa). (n = number of samples).

		^{210}Po (Bq kg^{-1})	^{210}Pb (Bq kg^{-1})
Cladonia convoluta ($n = 3$)	Mean	297	194
	Min.	260	188
	Max.	334	200
Homalothecium sericeum ($n = 30$)	Mean	334	267
	Min.	188	113
	Max.	575	461
Pterogonium graciale ($n = 15$)	Mean	339	205
	Min.	142	94
	Max.	620	283
Isothecium alopecuroides ($n = 3$)	Mean	317	210
	Min.	201	135
	Max.	456	284
Didymodon acutus ($n = 11$)	Mean	366	263
	Min.	194	136
	Max.	630	454
Hypnum lacunosum ($n = 3$)	Mean	398	384
	Min.	360	347
	Max.	436	420
Syntrichia intermedia ($n = 3$)	Mean	893	571
	Min.	680	445
	Max.	1125	724
Syntrichia ruralis ($n = 3$)	Mean	365	284
	Min.	316	268
	Max.	414	300

Table 4
Mean, minimum (Min) and maximum (Max) of ^{210}Po and ^{210}Pb (Bq kg^{-1}) in lichen and moss species collected in Seyitömer – Tunçbilek (Kütahya). (n = number of samples).

		^{210}Po (Bq kg^{-1})	^{210}Pb (Bq kg^{-1})
Cladonia convoluta ($n = 3$)	Mean	185	113
	Min.	183	101
	Max.	186	125
Homalothecium sericeum ($n = 10$)	Mean	192	145
	Min.	144	102
	Max.	254	193
Cladonia foliacea ($n = 3$)	Mean	192	126
	Min.	169	97
	Max.	206	146
Pleurochatae squarrosa ($n = 3$)	Mean	252	182
	Min.	245	175
	Max.	259	189
Hypnum lacunosum ($n = 4$)	Mean	243	186
	Min.	193	138
	Max.	313	257
Syntrichia intermedia ($n = 3$)	Mean	376	244
	Min.	370	203
	Max.	382	285

The number of samples is different for each sampling site as shown in Tables 2–4. Lichens of similar composition are not easy to find, because of the differences caused by fields on which lichens are growing.

There were significant differences in concentrations of ^{210}Po and ^{210}Pb among the three areas (ANOVA, $P < 0.001$). The differences observed between the different sampling stations could be in connection with various ecological conditions and individual lichen and moss characteristics. In addition, as indicated by Poikolainen (2004), the precipitation of rainwater affect on the accumulation, mobility and leaching of elements in mosses. Yatağan (Muğla) sampling area is under the influence of Mediterranean climate with cool wet winters and warm to hot, dry summers. On the other hand, climate type of Soma (Manisa) and Tunçbilek – Seyitömer (Kütahya) areas is known as continental. *C. convoluta* which is found on soil and rocks and *H. sericeum* which is collected under trees are commonly available in our study sites. It is observed that ^{210}Po and ^{210}Pb concentrations in *C. convoluta* and *H. sericeum* collected from Yatağan are higher than those samples from the other sites. On the contrary, Poikolainen (2004) indicated that the physiological and morphological properties or behavior of even the same moss species may be changed from place to place. This situation can influence the accumulation properties of the same species.

The maximum ^{210}Po and ^{210}Pb activities were measured in *T. tortuosa* which found only in Yatağan site as shown in Table 2. Meanwhile, the maximum ^{210}Po and ^{210}Pb activities were measured in *S. intermedia* in Soma and Seyitömer. *S. intermedia* and *T. tortuosa* which are growing on stone, indicated the maximum accumulation capacity as shown in Fig. 3. The highest ^{210}Po and ^{210}Pb uptake in these species could be related to effect of the biological characteristics. On the other hand, it is believed that changes in the vegetation cover have an effect on ^{210}Po and ^{210}Pb concentrations in mosses. These moss species collected from the open field were exposed to the direct radioactive deposition. Thus, uptake of the radionuclides is not influenced by trees or other vegetation. ^{210}Po concentrations were found to be higher than ^{210}Pb concentrations for all sampling stations, as shown in Fig. 3.

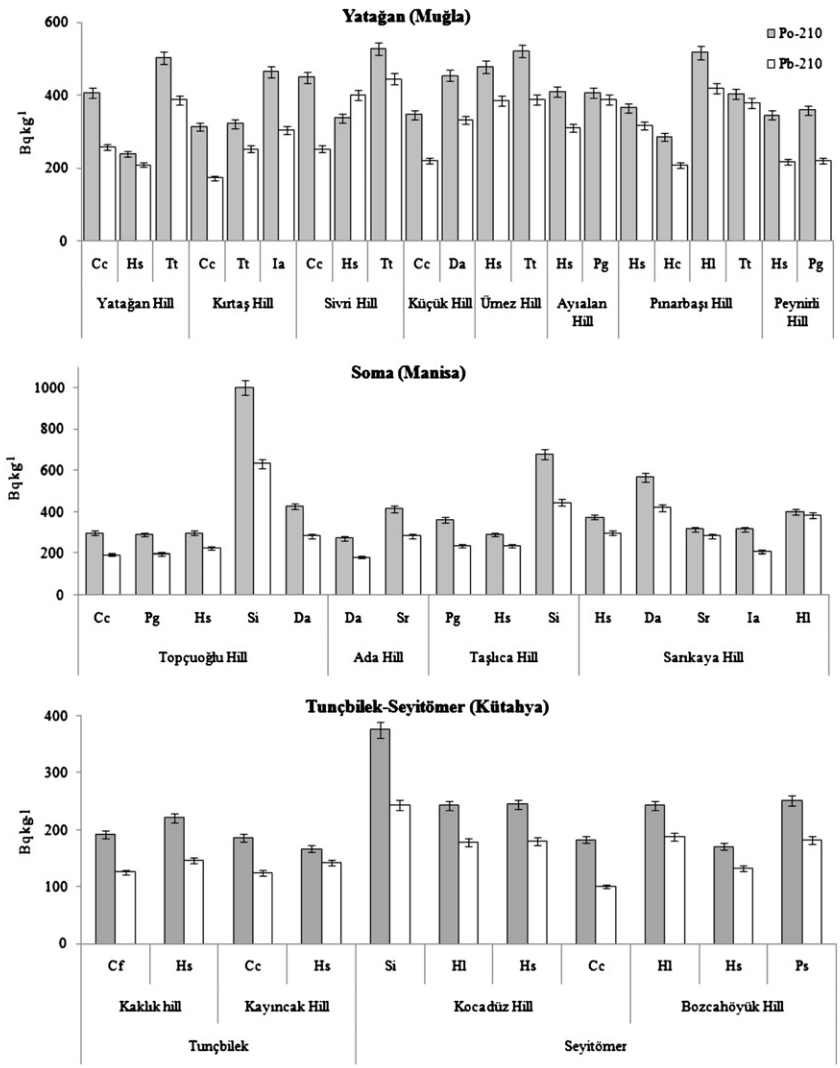

Fig. 3. Mean concentrations of ^{210}Po and ^{210}Pb in mosses and lichens collected from the study sites.

Like two moss species (*S. intermedia* and *T. tortuosa*), *C. convoluta* lichen species as indicated in the study by Uğur et al. (2003) is evidently sensitive to exposure atmospheric concentrations of radionuclides as shown in Fig. 3. Although *C. convoluta* has been commonly found for Yatağan area, the capture efficiency (for ^{210}Pb and ^{210}Po) of this lichen species is lower than some moss species (*T. tortuosa*, *D. acutus*, *I. alopecuroides*, *H. lacunosum*). Besides, some moss species have been widely observed in the other sampling areas than *C. convoluta* lichen species. Therefore, in these regions, mosses seem to be more reliable as biomonitors of atmospheric deposition of radionuclides (^{210}Pb, ^{210}Po). Additionally, it is known that some species of moss were more tolerant of atmospheric pollution. Szczepaniak and Biziuk (2003) stated that many moss species are geographically widespread and grow under different environmental conditions, even in industrial and urban areas.

$^{210}Po/^{210}Pb$ activity ratio (1.04–1.81) was found to be higher than unity for all lichen and moss samples. The main source of ^{210}Po and ^{210}Pb is the ^{222}Rn decay in the atmosphere but around the power plant they come also from escaping fly ash in which ^{210}Po concentration is about two times as high as ^{210}Pb. There exists an additional source of ^{210}Po around the plant due to the chimney gases, as well (Yener and Uysal, 1996; Uğur et al., 2003). All these effects are clearly observed in our results as high total ^{210}Po and ^{210}Pb activities in the samples. In our earlier study (Uğur et al., 2003), we have reported that soil samples were collected and analyzed in order to evaluate any possible enrichment in ^{226}Ra and ^{210}Pb concentrations in soil profiles due to coal-fired power plant (CPP) in Yatağan (Muğla). ^{226}Ra and total ^{210}Pb were measured in cultivated and undisturbed soil profiles. ^{226}Ra levels were comparable with those at control sites while ^{210}Pb flux was higher than regional averages (Uğur et al., 2003). This would support that the major source of ^{210}Po and ^{210}Pb could be significant amount of release from coal-fired power plant. Some other works conducted on ^{210}Pb activity concentrations in literature show that ^{210}Pb atmospheric deposition is increased in

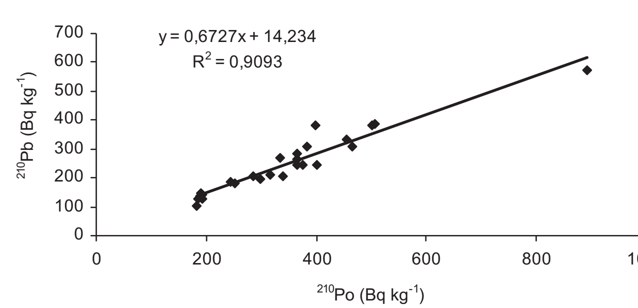

Fig. 4. Correlation between ^{210}Po and ^{210}Pb concentration in lichen and moss species.

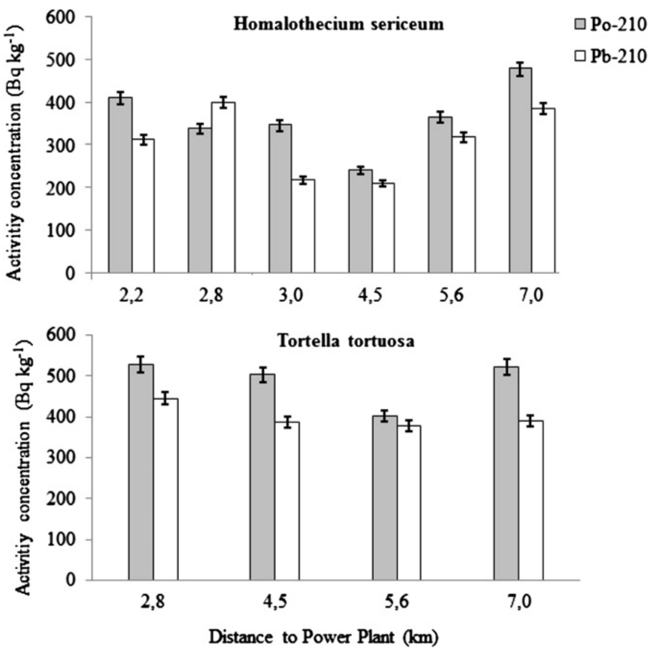

Fig. 5. The relationships between the activity concentrations and distances from Yatağan power plant for *Tortella tortuosa* and *Homalothecium sericeum*.

vicinity of coal-fired power plant (Delfanti et al., 1999; Uğur et al., 2003, 2004; Krmar et al., 2009).

Unlike higher plants, lichens and mosses do not have a root system (Steinnes, 1989; Bargagli et al., 2002; Real et al., 2003). They are strongly dependent for their mineral nutrients on material deposited through wet and dry deposition to the plant surface (Sloof, 1993). Therefore, pollutants can not enter the tissues from soil (Real et al., 2003).

The relationship between ^{210}Po and ^{210}Pb concentration for the current dataset is shown in Fig. 4 and their concentrations are linearly correlated ($r = 0.954$, $p < 0.001$). The MINITAB Statistical software was used to evaluate the correlation.

Some of the biomonitoring studies throughout the world indicated that the concentrations of various elements in lichens and mosses have been shown to be inversely correlated with the distance from pollution sources (Saeki et al., 1977; Garty and Ammann, 1987; Türkan et al., 1995; Dillman, 1996; Fernandez et al., 2007). In the contrary to the other studies, in this research, it has been found that relationships between distance from the plant and contamination in mosses and lichens are irregular as shown in Fig. 5. *H. sericeum* and *T. tortuosa* collected from different hills were around the coal-fired power plant in Yatağan site. The results compared with values corresponding to the surroundings of the focal point of the pollution. The direction of prevailing winds affects a decrease in concentration of pollutants with increasing distance from the source. Conti and Cecchetti (2001) reported that the direction in which pollutants are transported by the wind is most surely fundamental in determining their main fallout points. Therefore, it is thought that these chaotic relationships could be linked to wind ways. Besides, in 7 km, ^{210}Po and ^{210}Pb activity concentrations increase with respect to the other distances. The observed increase was due to the sampling area which is close to ash stacks.

4. Conclusion

For 100 years, world has been using of coal as a heat source for electric power generation. Therefore, it will affect the distribution of a variety of radioactive elements into the environment. It is projected that the coal combustion will be increased throughout the world during the next century. For this reason, it is important to know the enhancement of some natural radionuclides such as ^{210}Po and ^{210}Pb around the coal-fired power plants near population areas.

In this study, ^{210}Po and ^{210}Pb levels were investigated in lichen and moss samples collected from a wide area around the coal-fired power plants in Western Turkey. The activity concentrations of ^{210}Po and ^{210}Pb reported here have been discussed in terms of the use of lichen and moss species as a biomonitor for the sampling stations. It has been found that these plants can be used as biomonitors of ^{210}Po and ^{210}Pb deposition. It is obvious that different moss and lichen species collected in the same biotope can exhibit differences in their accumulation properties. In general, moss species appear to accumulate more ^{210}Po and ^{210}Pb than lichen species. This observation supports their continuous use as biomonitors and possible control measure for these radionuclides in the study sites. However, we found that the activity concentration of ^{210}Po and ^{210}Pb in some moss species seem more clearly indicate the emission sources and differences in radionuclide deposition than lichens for these sampling areas. One of the moss species (*S. intermedia*) is the most suitable and available biological monitor of the fallout pattern in Soma (Manisa) and Seyitömer (Kütahya) sites. According to the results, ^{210}Po and ^{210}Pb concentrations were found in the moss (*S. intermedia*) samples higher than the other moss and lichen species. However, *S. intermedia* could not be found in Yatağan region. Therefore, different moss species collected to evaluate in their accumulation properties in Yatağan (Muğla). *H. lacunosum* was found as the most suitable biomonitor for evaluation of pollution in Yatağan (Muğla). The results obtained about the differences between mosses and lichens as accumulation biomonitors depend on the species used in the studies and the environment of the studied area. Canopy is also an important factor causing differences in the concentrations of radionuclides (Uğur et al., 2003; Poikolainen, 2004). In biomonitoring studies, lichens and mosses should be collected from open areas not affected by shielding of trees.

Acknowledgment

This research work is supported by grants from the Ege University Scientific Research Project Contract No: 2002 NBE 005.

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