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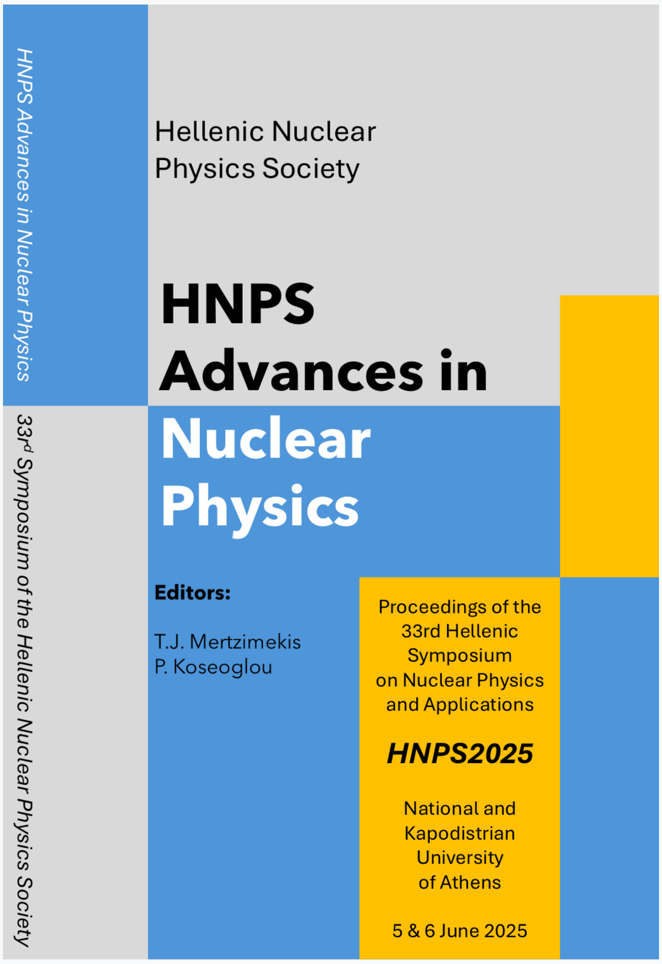

Soil radioactivity in urban parks of Piraeus

ELENI KAPSOKOLI, Foivos Panagiotis Gelatsoras, Georgios Siltzovalis, Ioannis Madesis, Theo J. Mertzimekis

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ARTICLE

Soil radioactivity in urban parks of Piraeus

E. Kapsokoli,* F.P. Gelatsoras, G. Siltzovalis, I. Madesis, and T.J. Mertzimekis

Department of Physics, National and Kapodistrian University of Athens, Athens, Greece

*Corresponding author: kapseleni@gmail.com

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Abstract

Assessment of natural and artificial radioactivity in soil is essential for understanding environmental radiation exposure and potential health risks. In the present study, the levels of natural and artificial radioactivity in twenty (20) urban parks in Piraeus and the surrounding areas have been assessed extending a study conducted by Gelatsoras et al. in urban parks in the wider Attica region. The focus has shifted on the industrial area around the largest Greek port, which is also a major touristic and transportation hub. High-resolution γ-ray spectroscopy was carried out in properly prepared samples at the recently upgraded Advanced Laboratory for Environmental Radiation Technology (ALERT) at National and Kapodistrian University of Athens. The measured specific activities of NORM (^{40}K, U- and Th-series), as well as of ^{137}Cs, the major Chernobyl fallout tracer, are reported. Overall, the results show a trend in agreement with the average background levels in Greece, with a few exceptions suggesting that further work is required.

Keywords: natural radioactivity; artificial radioactivity; γ-ray spectroscopy; NORM; ^{137}Cs

1. Introduction

Assessment of natural and artificial radioactivity in soil is essential for understanding environmental radiation exposure and potential health risks. Regarding Greece, there is a considerable number of studies focusing on both natural and artificial radioactivity. Shortly after the Chernobyl fallout, the first measurements in Greek soils were reported by Simopoulos [1] and Kritidis et al. [2]. A total of 1242 samples were collected by Simopoulos from all over Greece, and measurements of ^{137}Cs were conducted using a NaI detector. The ground activity range was 0–137 kBq/m^2. For 252 samples with the highest ^{137}Cs activity, measurements of ^{40}K were also conducted using a Germanium detector, reporting values in the range 55–1570 Bq/kg. One year later, Kritidis et al. [2] published a study on the estimated dose received by the Greek population during 1986–1987 due to the radioactive fallout from the Chernobyl accident, conducting measurements on thousands of water, air, and food samples. The total ^{137}Cs activity in Greek soil ranged from 3 to 45 kBq/m^2. In 1996, Anagnostakis et al. [3] published a study on natural radioactivity, specifically on the isotopes ^{226}Ra, ^{232}Th, and ^{40}K. A total of 1440 soil samples were analyzed, collected from across Greece and from the surface layer of soils up to a depth of 1 cm. The specific activities were 25 ± 19 Bq/kg, 21 ± 16 Bq/kg, and

355 ± 220 Bq/kg, respectively. In 2004, Arapis and Karantinos [4] published a study on the amount of ^{137}Cs in areas of Northwestern Greece ten years after the Chernobyl accident. Soil samples were collected from four regions between Grevena and Kalambaka (areas initially most affected). The mean ground activities per area were 62.1 kBq/m^2 in Karpero, 28.7 kBq/m^2 in Kalambaka, 31.9 kBq/m^2 in Rizoma, and 15.5 kBq/m^2 in Krinitsa. In 2013, Eleftheriou et al. [5] conducted a study on radioactivity and heavy metal concentrations in sediment samples from the seabed of the Strait of Northwestern Salamina (northern Saronikos Gulf). The specific activities ranged from 2.3 to 64.1 Bq/kg for ^{226}Ra, 5.2 to 22.9 Bq/kg for ^{232}Th, 0.3 to 6.6 Bq/kg for ^{235}U, 61.8 to 377.3 Bq/kg for ^{40}K, and 0.3 to 6.6 Bq/kg for ^{137}Cs. In 2021, Mertzimekis et al. [6] studied the levels of radioactivity in soils collected from the Zografou campus of the National and Kapodistrian University of Athens, using the portable AMESOS (Athens MobilE γ-SpectrOmetry System) spectrometer (NaI(Tl) detector). They conducted 20 in-situ measurements and calculated the areal activities of ^{226}Ra, ^{40}K, and ^{137}Cs. The ground activity of ^{226}Ra ranged from 0.240 kBq/m^2 to 0.749 kBq/m^2, with a weighted average value of 0.478 ± 0.002 kBq/m^2. For ^{40}K activities ranged from 4.64 kBq/m^2 to 13.87 kBq/m^2, with a weighted average value of 7.10 ± 0.01 kBq/m^2, while for ^{137}Cs activities ranged from 0.211 kBq/m^2 to 0.511 kBq/m^2.

In 2023, Gelatsoras et al. [7] published a study focusing on the radioactivity levels in urban parks in the metropolitan areas of Athens, Barcelona, and Bucharest. The specific activities of ^{40}K, ^{232}Th and ^{238}U ranged from 87.37 ± 4.51 Bq/kg to 302.36 ± 15.48 Bq/kg, 6.48 ± 0.43 Bq/kg to 16.78 ± 1.14 Bq/kg and 9.89 ± 0.70 Bq/kg to 30.00 ± 2.01 Bq/kg, respectively, while the maximum activity of ^{137}Cs was found 85.93 ± 3.64 Bq/kg in the metropolitan NKUA campus in Athens. In the present study, we have undertaken an extension of the previous study to include radiological measurements in soils from Piraeus urban parks in the wider Athens metropolitan region. Piraeus is a major port of Europe, a transportation node and a touristic hub, which has been impacted by dense construction and suffered significant loss of green spaces over the past 50 years. Piraeus urban parks can serve as representative locations to assess the natural radiological background and the level of persistence of the Chernobyl fallout in the soils.

2. Materials and Methods

We collected in total twenty (20) samples from urban parks in Piraeus (Fig. 1). We preferred undisturbed soils, wherever possible. The samples were dried for 24 h, sieved using a 2 mm sieve, packed in cylindrical 120 mL PVC containers and weighed (Fig. 2). The cylindrical containers were sealed and left for over a month to reach equilibrium [8].

Figure 1. Sampling locations in urban Piraeus area.

Figure 2. Sampling preparation.

Figure 3. The HPGe semiconductor detector TIGER at ALERT.

High-resolution γ-ray spectroscopy measurements were conducted at the ALERT Lab of the Department of Physics at NKUA, using the 40% rel. eff., shielded HPGe TIGER detector (see Fig. 3). Spectra analysis was conducted using the SPECTRW software [9]. Bulk reference samples were used to calibrate the spectrometer and deduce specific activities for NORM (^{40}K, U- and Th-series) and anthropogenic (^{137}Cs) isotopes.

3. Results

The range of specific activity values for each isotope is presented in Table 1.

Table 1. Specific activities of the isotopes

Isotope (photopeak)	Minimum activity (Bq/kg)	Maximum activity (Bq/kg)
^{226}Ra (186 keV)	below detection limit	15.86 ± 1.60
^{214}Pb (296 keV)	4.76 ± 0.40	12.85 ± 0.88
^{214}Pb (352 keV)	3.99 ± 0.29	12.43 ± 0.74
^{214}Bi (609 keV)	4.97 ± 0.39	13.92 ± 0.90
^{214}Bi (1120 keV)	4.87 ± 0.69	14.69 ± 1.59
^{214}Bi (1764 keV)	below detection limit	13.44 ± 1.27
^{228}Ac (339 keV)	5.08 ± 0.46	15.63 ± 1.08
^{228}Ac (911 keV)	5.20 ± 0.45	14.79 ± 0.98
^{228}Ac (969 keV)	6.12 ± 0.66	16.42 ± 1.38
^{212}Pb (239 keV)	5.51 ± 0.29	13.76 ± 0.64
^{208}Tl (584 keV)	2.12 ± 0.14	5.49 ± 0.30
^{208}Tl (2615 keV)	1.90 ± 0.23	7.24 ± 0.58
^{40}K (1461 keV)	148.05 ± 5.69	324.08 ± 9.75
^{137}Cs (662 keV)	below detection limit	37.98 ± 0.91

In addition, histograms and maps of specific activities are presented in Figs. 4–11 to provide a more complete picture of the radiological landscape in the study area.

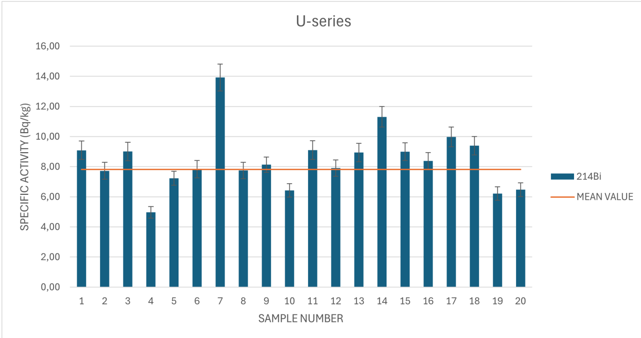

Figure 4. Specific activity of U-series (blue histogram) and weighted average of specific activity (orange line).

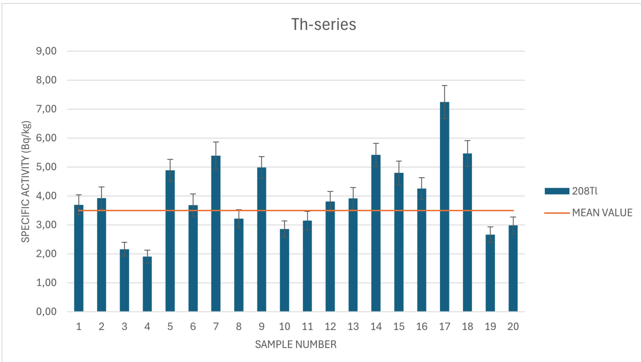

Figure 5. Specific activity of Th-series (blue histogram) and weighted average of specific activity (orange line).

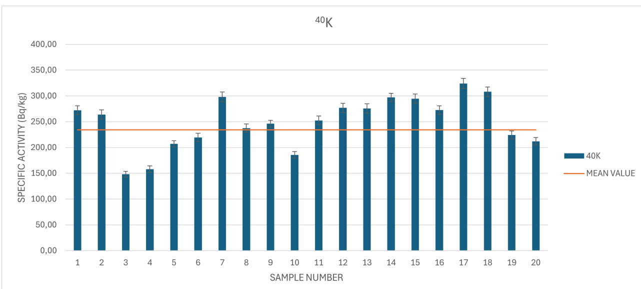

Figure 6. Specific activity of ^{40}K (blue histogram) and weighted average of specific activity (orange line).

4. Discussion and Conclusions

This study presents the first systematic measurements of environmental radioactivity levels in the civic area of Piraeus. Urban parks, which are characterized by virtually undisturbed soils, were selected as sampling sites.

The results show that the specific activities are generally low and mean no risk to the population, as they do not exceed the official dosage limits for the general population. The measured ^{137}Cs specific activity is lower than the average value reported for Greek soils, while ^{40}K levels seem to be lower compared to rural areas, especially those with agricultural activities [3, 10–12]. The present results are also in good agreement with previous measurements conducted in urban parks of Athens,

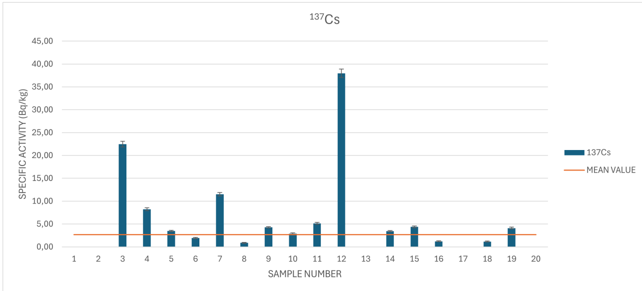

Figure 7. Specific activity of ^{137}Cs (blue histogram) and weighted average of specific activity (orange line).

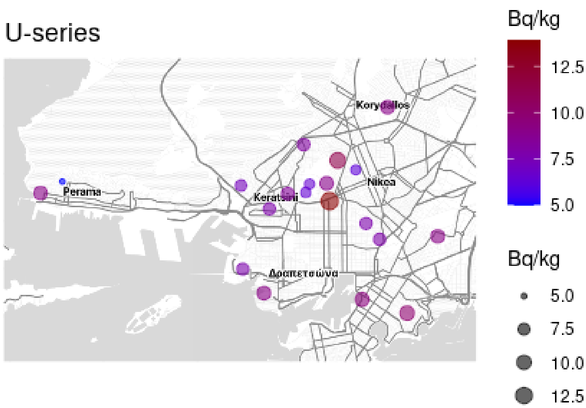

Figure 8. A map of Piraeus showing the specific activity of the U-series isotopes in the sampling areas.

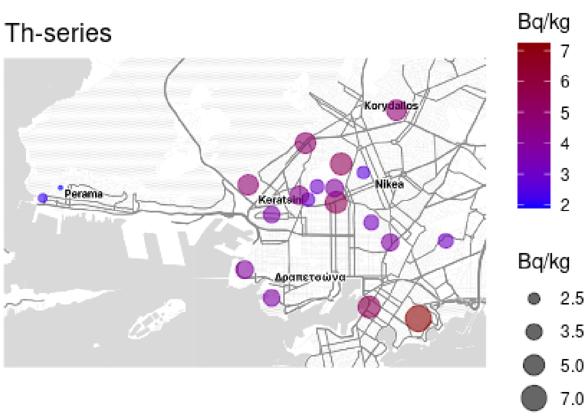

Figure 9. A map of Piraeus showing the specific activity of the Th-series isotopes in the sampling areas.

showing similar NORM activity levels. The specific activity of ^{137}Cs is lower than that reported for the wider Attica region [7], most likely due to its higher transport rate into the sea.The highest specific-activity values for ^{137}Cs were observed in samples 3 and 12. These samples require further

Figure 10. A map of Piraeus showing the specific activity of the isotope ^{40}K in the sampling areas.

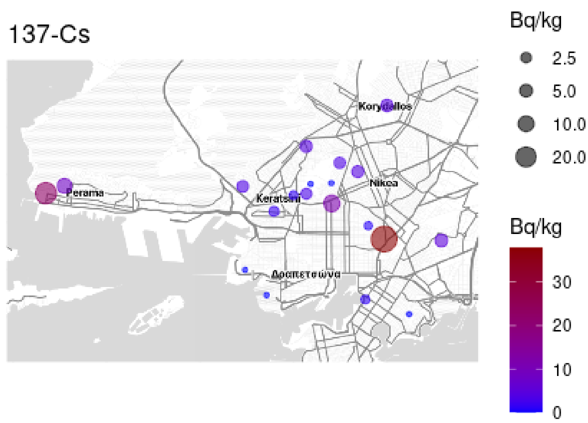

Figure 11. A map of Piraeus showing the specific activity of the isotope ^{137}Cs in the sampling areas.

scrutiny as to the soil composition and origin.

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