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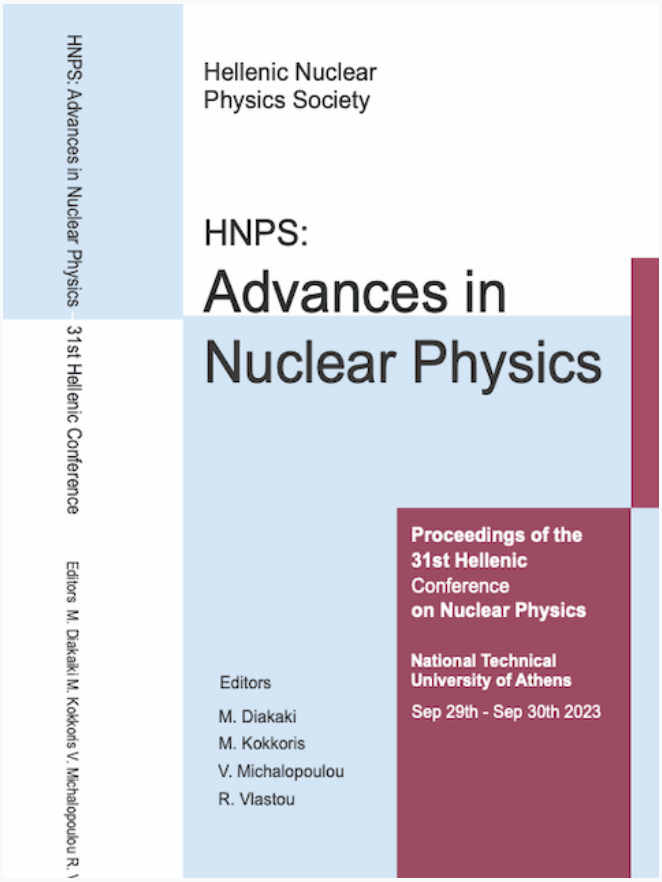

A Study of natural radioactivity in urban parks

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A study of natural radioactivity in urban parks

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Abstract Urban parks are typically undisturbed natural locations inside metropolitan areas, attracting human recreation activities. The present work focuses on studying the radioactivity levels in urban parks in the metropolitan areas of Athens, Barcelona, and Bucharest to establish a baseline of the overall environmental load and the associated contribution to background radiation dose levels. A total of 25 soil samples were collected, prepared, and measured with high-resolution gamma spectroscopy at the Environmental Radioactivity Laboratory of NKUA. Specific activities for naturally occurring isotopes (^{40}K, U-, and Th-series) and anthropogenic radiocesium have been deduced. The results are correlated to the level of human intervention in the parks but also show that traces of ^{137}Cs from the Chernobyl fallout are still present in the most undisturbed soils, reaching values up to 86±4 Bq/kg. All the data has been used to populate a GIS-based informational database featuring various layers of storyboards and metadata.

Keywords Environmental radioactivity, γ-ray spectroscopy, urban parks, ^{137}Cs, NORM

INTRODUCTION

In this work, we explore a significant research gap in natural radioactivity by focusing on urban environments in Greece. There are many publications of research concerning foreign countries from all over the world. Liu et al. in 2020 compared the average specific activities in various parks in China [1]. Phachirarat Sola [2] in 2021, analyzed 223 sand samples taken from seven provinces in northeastern Thailand and calculated that the specific activity of ^{40}K is 323±168 Bq/kg, ^{226}Ra is 36±10 Bq/kg, while ^{232}Th is equal to 2.64±0.58 Bq/kg. Several other works exist in literature for Europe and the world.

Table 1. *The comparison of specific radioactivity measurements by Liu et al. [1]*

	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
Parks average	544	30.2	47.2
National average	584	38.5	49.1

In Greece, there is an abundance of published research on environmental radioactivity, most of them dating back to 2004. In 1989, three years after the accident at the Chernobyl nuclear power plant in eastern Ukraine, the first measurements in Greece were published by Simopoulos [3]. 1242 samples were collected from all over Greece, of which 37 were from Attica. The average surface activity of ^{137}Cs in Attica was 1.2 kBq/m^2. Three years later, Kritidis et al. [4] reported that rainy days after the accident played a role in the enrichment of the soil with radionuclides. Total cesium in Greek soil had a surface activity in the range of 3–45 kBq/m^2. In 1996, Anagnostakis et al. [5] analyzed a total of 1440 soil samples, collected throughout Greece from the surface soil layer to a depth of 1 cm and studied for natural radioactivity ^{226}Ra, ^{232}Th, and ^{40}K. The sampling period was seven distinct periods of 1986–1992. The specific activities were 25±19 Bq/kg, 21±16 Bq/kg, and 355±220 Bq/kg, respectively. Ten years after the Chernobyl accident, Arapis & Karandinos [6] collected soil samples from four sites between Grevena and Kalambaka, the areas that had been most affected initially in 1986. The mean concentrations of ^{137}Cs per site were found to be: 62.1 Bq/kg in Karpero, 28.7 Bq/kg, in Kalambaka,

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31.9 Bq/kg, in Rizoma, and 15.5 Bq/kg in Krinitsa. In 2021, Mertzimekis et al. [7] conducted a study on the metropolitan Zografou campus of the National and Kapodistrian University of Athens. Through the analysis of 20 on-site measurements obtained with the AMESOS portable spectrometer, they recorded the concentrations of ^{226}Ra, ^{137}Cs, and ^{40}K. It is reported that the spatial activity of ^{40}K, with a mean value of 7.10±0.01 kBq/m^2, agrees with previous publications. Furthermore, the radiocesium measurements ranging between 0.211–0.511 kBq/m^2 are significantly lower than those recorded in Athens immediately after Chernobyl or later, indicating a significant reduction in its retention in soils. It is evident that apart from the campus region, no recent systematic survey has been conducted on the radiation levels in Attica.

EXPERIMENTAL DETAILS

We collected 23 samples from urban parks in the metropolitan Athens region, as well as one sample from Barcelona and one sample from Bucharest (the latter measurements are not reported in the present work). Whenever possible, we preferred undisturbed soils. The collected samples underwent several stages of preparation before being measured for their specific activities. They were air-dried to 60º C for 24 h and then any organic admixtures and large objects (e.g. gravel) were removed from the bulk material. The samples were finally sieved to a particle size of 2 mm and packed into cylindrical 120 ml PVC containers.

High-resolution γ-ray spectroscopy measurements were conducted in the HPGe spectroscopy station at NKUA (*TIGER*). The duration for each sample measurement was 80’000 s. Bulk reference samples were used to calibrate the spectrometer. Spectra analysis was conducted using the SPECTRW software [8]. The specific activities for the following isotopes were deduced for common NORM (^{40}K, Th- and U-series) and the anthropogenic ^{137}Cs.

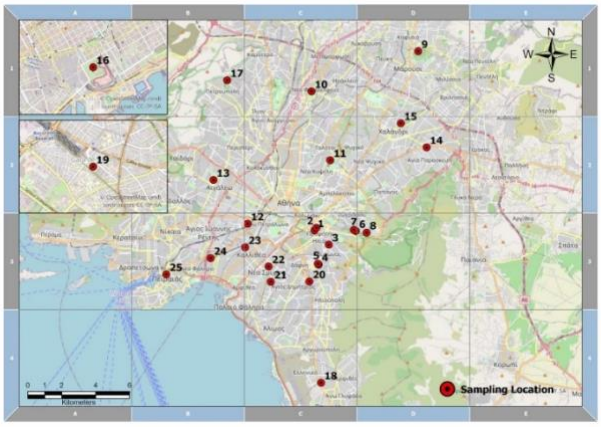

Figure 1. *Sampling locations. Insets show Barcelona and Bucharest locations.*

Figure 2. *The NKUA spectrometer TIGER*

RESULTS AND DISCUSSION

The range of specific activity values for each radioisotope is shown in Table 2. The results refer to samples of dry mass.

Table 2. *Specific activities (Bq/kg) for ^{208}Tl, ^{212}Pb, ^{214}Bi, ^{214}Pb, ^{137}Cs and ^{40}K*

Isotope	Energy (keV)	Minimum activity (Bq/kg)	Maximum activity (Bq/kg)
^{137}Cs	661.7	below detection limit	85.93 ± 3.64
^{40}K	1460.8	87.37 ± 4.51	302.36 ± 15.48
^{214}Pb	295.2	10.35 ± 0.95	29.24 ± 2.44

^{214}Pb	351.9	10.15 ± 0.71	30.23 ± 1.97
^{208}Tl	583.2	5.91 ± 0.35	14.88 ± 0.89
^{208}Tl	2614.5	6.48 ± 0.43	16.78 ± 1.14
^{212}Pb	238.6	15.43 ± 0.73	37.42 ± 1.77
^{214}Bi	609.3	9.89 ± 0.70	30.00 ± 2.01

To provide a complete picture of the radiological landscape in the study area, a boxplot, and two specific radioactivity maps are presented below.

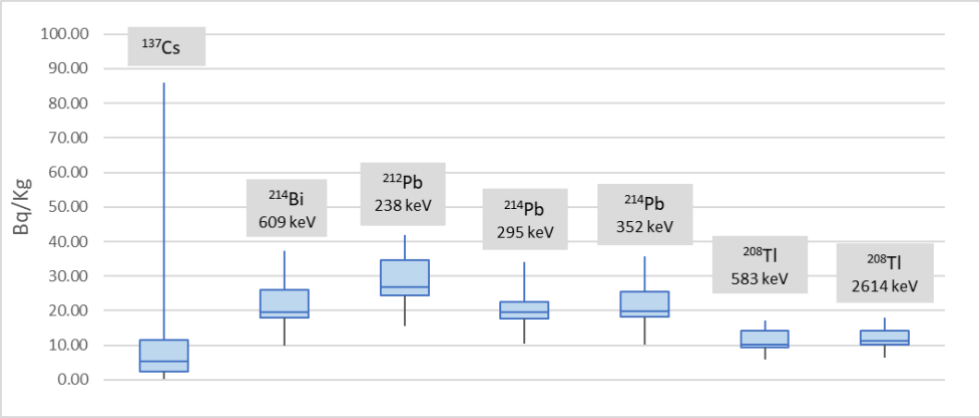

Figure 3. *Range of activities for ^{137}Cs, ^{214}Bi, ^{212}Pb, ^{214}Pb and ^{208}Tl*

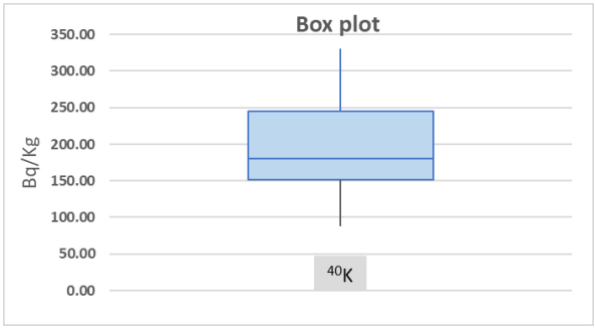

Figure 4. *Range of activity for ^{40}K*

CONCLUSIONS & FUTURE DIRECTIONS

We have estimated the levels of urban radioactivity in Athens metropolitan locations, many of which were studied for the first time. Additionally, we extended our measurements to include the metropolitan NKUA campus, enhancing the breadth of our dataset [7]. The sampling covered a large part of the prefecture of Attica, while the duration of the measurements was at least one day.

The maximum specific activity of ^{137}Cs is obtained in sample 7, which was taken from the soil of the campus of the University of Athens, with a value of 85.9±3.6 Bq/kg. It is rather expected to find the highest concentration in this sample because there is no strong disturbance of the soil in the area due to human activities. Therefore, the initial impact of the Chernobyl fallout on the site is almost exclusively influenced by the natural conditions of the site's evolution over the years. In conclusion, we say that the value of the specific activity of ^{137}Cs can be a measure of how undisturbed an area is.

In summary, it's worth noting that the activities associated with the natural radioactive decay series are generally lower than global averages [3,4,9]. The study of concentrations of natural and anthropogenic radioactive substances in urban parks is of interest and importance, both for the human population that is active in these parks and for the assessment of the impact on the urban environment in general. In this context, this work reinforces the importance of monitoring urban parks through the

non-invasive technique of gamma spectroscopy. The results were visualized using GIS software. The present radiological study will scale up to provide input to a novel GIS-based Information System, which is currently being tested to include additional features, story maps, and metadata.

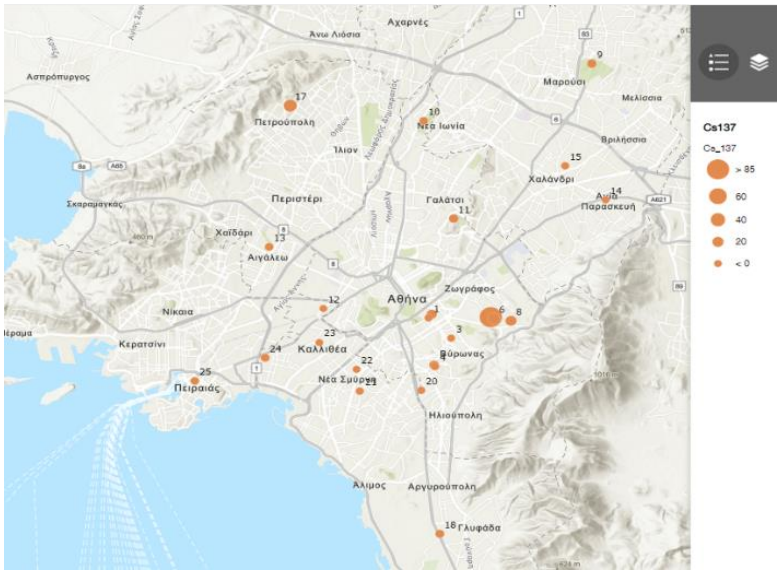

Figure 5. *A map of Attica showing the specific activity (in Bq/kg) of the isotope ^{137}Cs in the sampling areas*

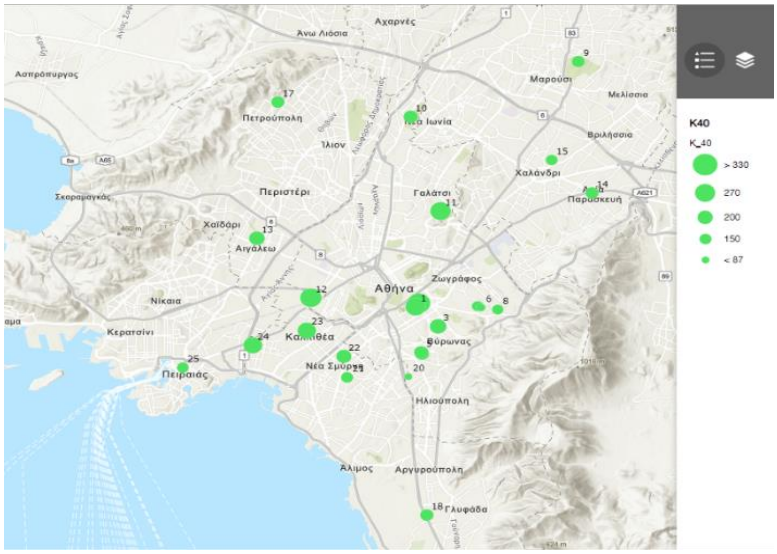

Figure 6. *A map of Attica showing the specific activity (in Bq/kg) of the isotope ^{40}K in the sampling areas*

Acknowledgments

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