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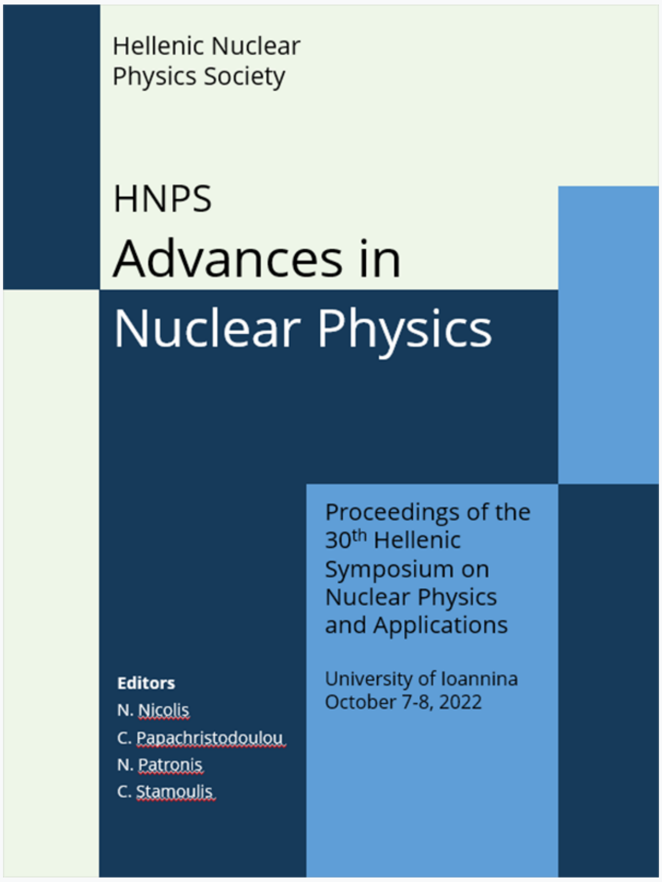

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NORM measurements at Kalloni and Gera Gulfs, Lesvos Island, Greece

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Abstract Natural radioactivity measurements were held in the beach sands of the two main gulfs (Gera, Kalloni) of Lesvos Island, Greece. These gulfs host thermal springs and are preferred tourist destinations throughout the year. Dose rates and concentrations of natural radioactivity (^{232}Th series, ^{226}Ra and ^{40}K) and ^{137}Cs were measured in-situ and in the laboratory by means of gamma-ray spectroscopy. Ten beach sand samples were collected from each gulf. The in-situ measurement for the dose rate determination was achieved via a portable NaI scintillation detector (SpriID). The activity concentration calculations were realized in the laboratory, with the use of a high purity germanium detector, and then they were also used to estimate dose rates. The in-situ measured and estimated dose rates were compared to verify the different approaches. The highest values (activity concentrations and dose rates) were found at the beaches of Kalloni Gulf compared to those of Gera Gulf.

Keywords: beach sand, natural radioactivity, gamma ray spectrometry, in-situ and lab measurements

INTRODUCTION

Natural radioactivity contributes to 80% of a year's effective exposure for humans [1]. Natural radioactivity can be divided into two main categories, terrestrial radioactivity (e.g. soil, rock, sediment, beach sand) and cosmic radiation. More specifically, natural radioactivity should be measured in sandy beach areas as these regions are characterized as ecological zones of great importance for leisure, recreational activities, and tourism. Moreover, there are areas exhibiting elevated radiation levels due to the geological background and geochemical processes. The high background radiation level of beach sands may be attributed to the presence of Th and U-bearing minerals such as monazite and zircons [2] or to volcanic activities [3]. Beach sand measurements regarding natural radioactivity have been performed worldwide [4]. Nevertheless, there are limited reports on natural radioactivity in Greek areas and especially on the island of Lesvos. Thus, in the present work the activity concentrations of terrestrial radionuclides (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) and ^{137}Cs were investigated on the volcanic island of Lesvos. Moreover, the absorbed dose rates were both measured and calculated following two different methodologies (in-situ and lab), so as to validate the different approaches and to determine the radiological risk to humans visiting the beach areas of the island.

SAMPLE PREPARATION AND FIELD WORK

A total of 20 beach sand samples were collected from the gulfs of Gera and Kalloni (Fig. 1). In-situ measurements using a portable NaI detector (SpriID) were also held at the same points to obtain absorbed dose rates data. For the sampling collection and sample preparation, the protocol proposed by

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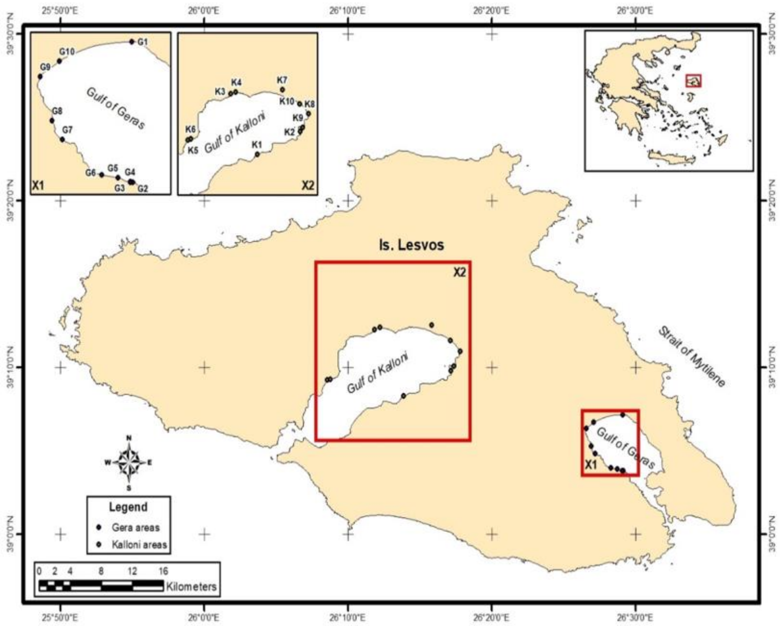

Figure 1. *The map of the sampling points*

[5] was followed, while the in-situ measurements were performed by adopting the guidelines of [6].

After the sample preparation, gamma-ray analysis was performed to determine the activity concentrations of natural radionuclides. Natural radioactivity and ^{137}Cs were measured using an HPGE detector with an efficiency of 45% relative to a 3΄΄× 3΄΄ NaI scintillator having a 1.8 keV resolution (FWHM) at the 1.332 MeV gamma ray of ^{60}Co. The appropriate calibrations and corrections (e.g. True Coincidence Summing effects) were also taken into consideration. Briefly, the laboratory system (HPGe) was calibrated using a multi-gamma source (Serial No AN-9481) [6], which was in the same geometry as the samples. The accuracy of the method was certified by taking part in International Atomic Energy Agency inter-laboratory tests (ALMERA 2019, 2020, 2021) providing excellent results. The in-situ system (SpirID) was calibrated by the providing company (MIRION). All radionuclides were measured in the environmental radioactivity facility of the Water and Air Quality Laboratory, Department of Environment, University of the Aegean.

METHODOLOGY

The activity concentrations (Bq kg^{-1}) of natural radionuclides were converted to absorbed dose rates (nGy h^{-1}) so as to be compared with those measured by SpirID. The activity concentration, the dose rate results, as well as the uncertainty of the measurements (e.g., gamma-rays' intensity, the detector efficiency) were determined via Eqs (1-4):

$$AC = \frac{Net\ area}{I_{\gamma} \cdot \mathrm{FEPE} \cdot t \cdot m}, \tag{1}$$

$$\delta_{AC} = AC \cdot \sqrt{\left(\frac{\delta_{net\ area}}{net\ area}\right)^2 + \left(\frac{\delta_m}{m}\right)^2 + \left(\frac{\delta_{FEPE}}{FEPE}\right)^2}, \tag{2}$$

$$D = A \cdot {}^{40}K + B \cdot {}^{226}Ra + C \cdot {}^{232}Th, \tag{3}$$

$$\delta_D = \sqrt{(A \cdot \delta^{40}K)^2 + \left(B \cdot \delta^{226}Ra\right)^2 + (C \cdot \delta^{232}Th)^2}, \tag{4}$$

where, AC is activity concentration (Bq kg^{-1}), Net area is the gamma-ray counts, I_{γ} is the gamma-ray intensity, FEPE is the full energy photo peak efficiency, t is the acquisition time (s), m is the mass of the sample (Kg), D is the dose rate (nGy h^{-1}), A= 0.0417, B=0.462 and C = 0.604 are constants adopted from [1]. To clarify, SpirID provides equivalent dose rates (nSv h^{-1}), however they are converted by a factor of 1 to absorbed dose rates for the case of photons.

RESULTS AND DISCUSSION

The activity concentrations of ^{226}Ra, ^{232}Th series and ^{40}K ranged from 5 to 60 Bq kg^{-1}, 5 to 130 Bq kg^{-1} and 200 to 1200 Bq kg^{-1}, respectively (Fig. 2a,b). The ^{137}Cs values (not shown) were below 2 Bq kg^{-1} in all samples. The uncertainties of the aforementioned radionuclides were found to be 6%, 7%, 2% and 20%, respectively. The highest concentrations between the two gulfs were obtained in the gulf of Kalloni, as it was less sandy than the beach sand samples of Gera Gulf. The difference regarding activity concentrations may be also attributed to the geological background of the two gulfs. Analogous results were observed in a natural radioactivity survey held in the terrestrial part of Lesvos Island, where the north-eastern Lesvos (above Kalloni Gulf) was characterized by elevated activity concentrations compared to the south-eastern part [8, 9] (above Gera Gulf). Additionally, the elevated activity concentrations in the beach sand samples, were similar to the elevated natural radioactivity concentrations observed in other volcanic Greek islands (e.g. Milos) [8]. As shown in Fig. 2c, the estimated dose rates (via HPGe) were in good agreement (divergence below 30%) with the measured ones (in-situ measurements via SpirID). The absorbed dose rates were mostly within the range (30-109 nGy h^{-1}) reported in Greece. However, they were above the Greek mean value (56 nGy h^{-1}) [9], which can also be associated with the volcanic background of Lesvos, rich in natural radioactivity.

Similar results have been found in the island of Ikaria which is also located in north-east Aegean Sea and is characterized by volcanic intrusions and rocks [10]. More specifically, the ^{226}Ra concentrations of this work were similar to those of the southern coast of the island, rich in thermal springs. The activity concentrations of ^{232}Th and ^{40}K were within the ranges found in Ikaria Island. The absorbed dose rates of this work exhibited similar values with those found in the northern coast of Ikaria, characterized by granites and volcanic intrusions.

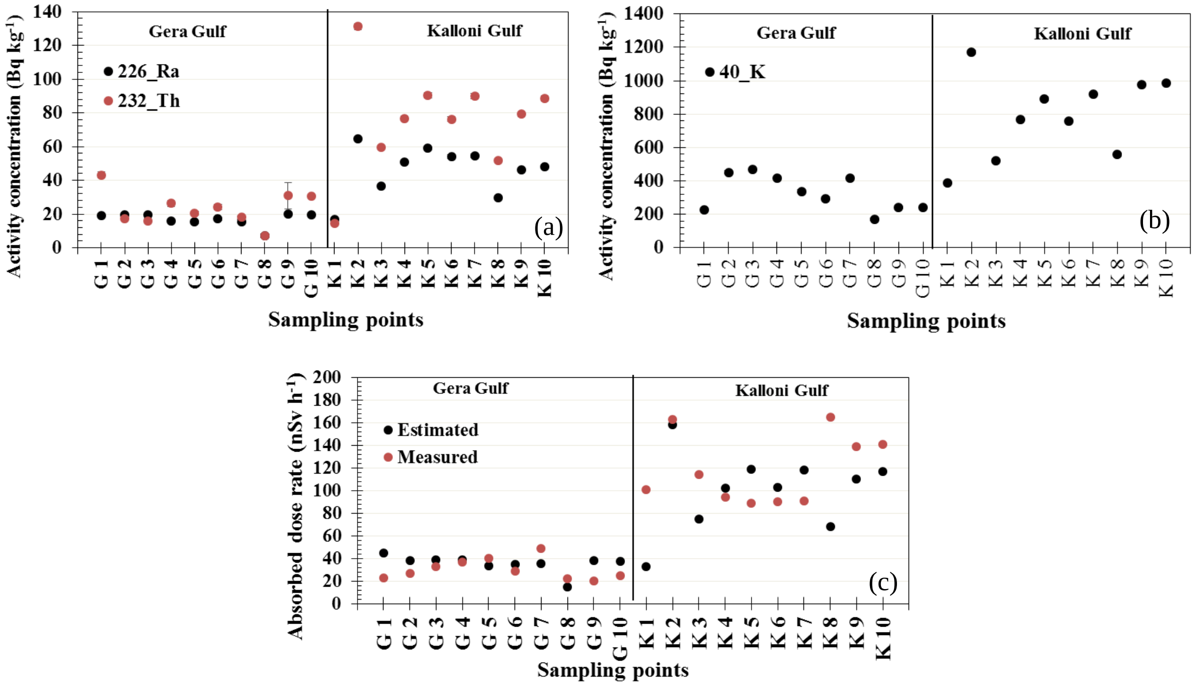

Figure 2. *(a, b) Activity concentrations of natural radionuclides determined at the beach sands of Gera and Kalloni Gulfs. (c) Estimated and calculated absorbed dose rates, obtained via HPGe and SpirID, respectively.*

CONCLUSIONS

Lesvos Island is of volcanic origin, and this is evident in the natural radioactivity concentrations obtained in the beach sand samples of Gera and Kalloni Gulfs. The north-eastern part of Lesvos shows higher activity concentrations and thus absorbed dose rates, compared to the south-eastern part, which can be attributed to a variety of reasons such as the geological background of the gulfs. A good agreement was also found between the different measuring systems and methodologies (HPGe, SpirID). Last but not least, the elevated absorbed dose rates of Lesvos gulfs were within the ranges mentioned in the literature for the case of Greece.

Acknowledgments

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