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Natural radionuclides in surface soils from Biritiba-Mirim reservoir, state of São Paulo

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INTRODUCTION

Natural radionuclides are widely distributed in many different minerals, and they are transferred to the soil composition by chemical weathering, however, human interference, mainly associated with agricultural activities and industrial emissions, can increase the activity concentrations of the radionuclides from the ^{238}U and ^{232}Th decay series and ^{40}K in surface soils. The Biritiba-Mirim reservoir (23°36'S 46°05'W) is located at the Upper Tiete water basin, which is responsible for water supply in the São Paulo Metropolitan area. Few studies aimed at the analysis of natural radionuclides in surrounding soils of the Brazilian water supply reservoirs, including the reservoirs of the Upper Tiete water basin. Some of this research is part of studies developed by the Environmental Radiometric Laboratory from the Nuclear and Energy Research Institute (LRA-IPEN) and aimed the evaluation of natural radionuclides activity concentrations in soils and sediments of the neighboring reservoirs (Ponte Nova, Jundiaí, and Taiaçupeba). The anthropogenic inputs of naturally occurrence radioactive materials should be managed to prevent risks either to humans or the biota, especially in disturbed environments, such as artificial water reservoirs. The main objective of this paper was to evaluate the activity concentrations of ^{238}U, ^{232}Th, ^{228}Ra, ^{228}Th, ^{226}Ra, and ^{40}K in surface soils from the Biritiba-Mirim reservoir. Moreover, this study aimed to verify the influence of soil physical-chemical parameters (clay, silt, and sand contents, pH, organic matter, cation exchangeable capacity, and total porosity), the lithological composition, and the land use on the activity concentrations of the natural radionuclides.

METHODOLOGY

- Surface soil samples (0-20cm) were collected in the wet period (November/2022) in 12 points, chosen according to the local lithology and land use, on the shore of Biritiba-Mirim reservoir (Fig. 1).

Fig. 1. Sampling illustrations.

- Soil grain size analysis, potential of hydrogen (pH), and total porosity (TP) were determined following the EMBRAPA soil chemical analysis manual. Soil organic matter (OM) and cation exchange capacity (CEC) were analyzed using loss-on-ignition, and exchangeable metallic cations/exchangeable acidity methods, respectively.

- The activity concentrations of ^{238}U and ^{232}Th were evaluated using Instrumental Neutron Activation Analysis (INAA).

- The activity concentrations of ^{228}Ra, ^{228}Th, ^{226}Ra, and ^{40}K were measured by gamma-ray spectrometry.

RESULTS AND DISCUSSION

The general results and the descriptive statistics of the natural radionuclides activity concentrations (Bq/kg) on the surface soils from the Biritiba-Mirim reservoir are shown in Table 1. All radionuclides analyzed have followed the normal distribution, accrediting the data for the ANOVA analysis.

Tab. 1. General results and descriptive statistics.

Descriptive statistics and comparisons						
	^{238}U	^{226}Ra	^{232}Th	^{228}Ra	^{228}Th	^{40}K
Mean	71.6	40.7	128	78.7	86.9	173
St. deviation	4.2	2.1	11	6.3	7.3	28
Amplitude	49-95	29-53	89-210	52-125	59-140	65-413
UNSCEAR	35	11-60	30	11-64	-	140-850
Jundiai	25-41	32-62	49-83	22-34	35-70	85-163
Ponte Nova	30-68	25-50	15-155	25-140	30-175	50-190
Taiaçupeba	29-62	34-64	53-100	54-93	54-111	184-417
Statistical analysis						
Shapiro-Wilk ρ	.814	.743	.065	.073	.113	.058
ANOVA Litho. ρ	.944	.479	.020*	.072	.137	.280
ANOVA Land ρ	.781	.748	.008*	.057	.093	.718

* p<0,05 rejects the null hypothesis, suggesting that the lithology and land use have a statistical effect on the ^{232}Th activity concentrations. p>0,05 on the Shapiro-Wilk test indicates analyte normal distribution.

The activity concentrations of ^{238}U and ^{232}Th have exceeded the mean levels reported by UNSCEAR and were slightly above the local reports in most of the samples analyzed. The activity concentrations of ^{228}Th, ^{228}Ra, ^{226}Ra, and ^{40}K remained moderately similar to respective comparisons. The statistical analysis has shown that only ^{232}Th is influenced by the effects of local lithology and land use. The natural radionuclides activity concentration variations between the lithology and land use, as well as the reservoir sampling map, are presented in Figure 2.

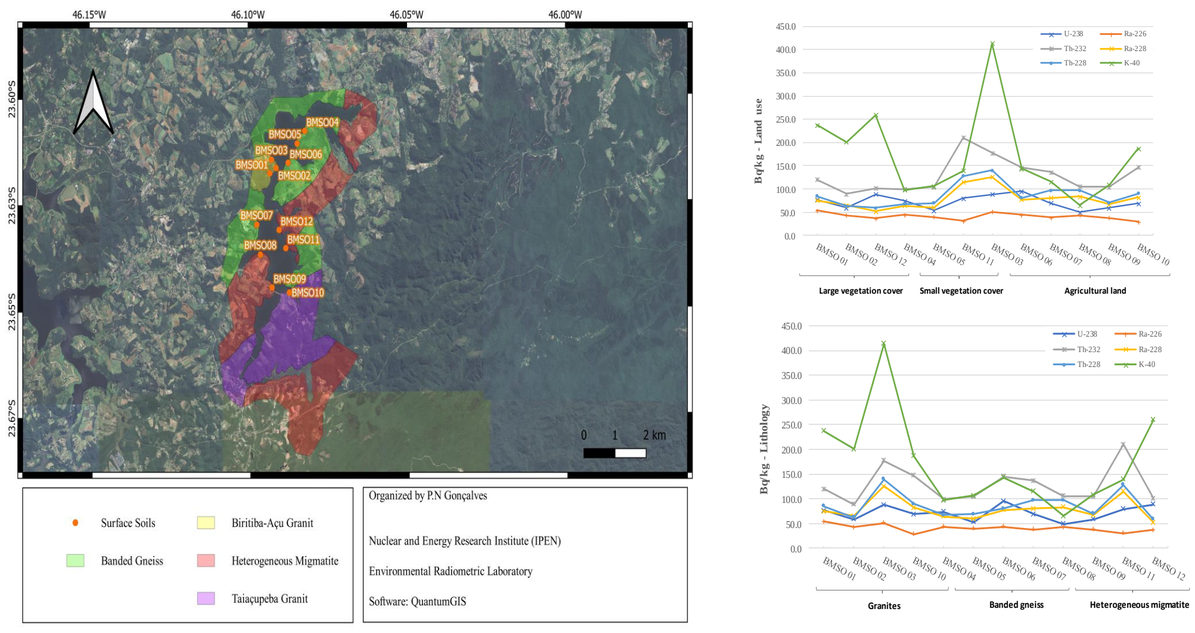

Fig. 2. Sampling map and natural radionuclide activity concentrations variations between different lithologies and land uses from the Biritiba-Mirim reservoir.

The results of the PCA and soil physical-chemical parameters are shown in Figures 3a and 3b, respectively. Figure 3b is displayed in two axes; the principal axis (on the left) represents values in percentage and includes sand, clay, silt, and TP; the secondary axis (on the right) represents CEC, pH, and OM.

(3a) **(3b)**

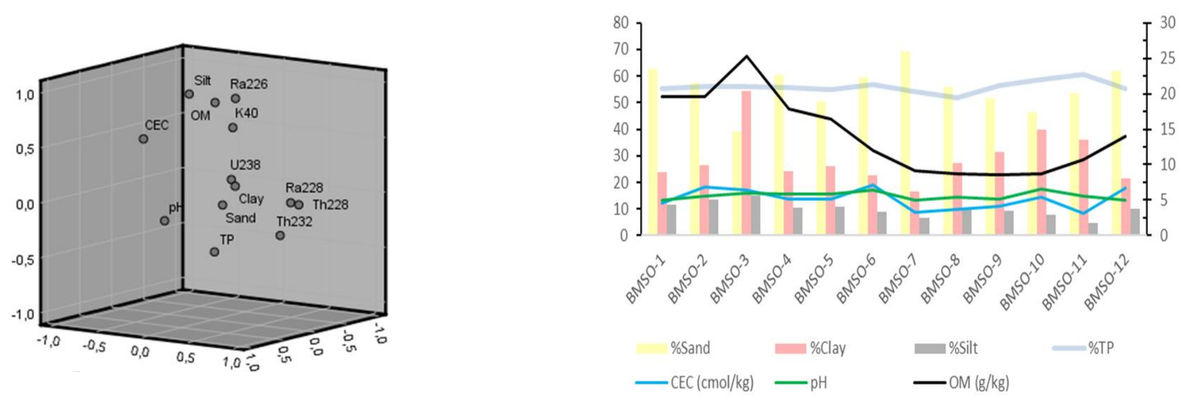

Fig. Results of the Principal Components of Analysis (3a) and Soil physical-chemical parameters (3b).

Figure 3b presents the PCA results; three principal components of analysis can be observed, and represent a cumulative variance of 78%, using the Varimax rotation method with Kaiser normalization. The results showed a strong correlation between ^{238}U and clay content, whereas ^{226}Ra and ^{40}K were associated with CEC, OM, and silt. The radionuclides from the ^{232}Th decay series (^{228}Ra and ^{228}Th) have a strong association with the principal component and stayed away from the other parameters, suggesting that the lithology, the land use, or the decay processes are controlling more significantly the activity concentrations of these radionuclides. The different associations between the two isotopes of radium reinforce this statement. The isotope ^{226}Ra from the ^{238}U decay series, despite having the same geochemical behavior as ^{228}Ra, is associated with other components.

CONCLUSIONS

The achievements of this study pointed to consistent results of ^{40}K, ^{226}Ra, ^{228}Ra and ^{228}Th in comparison with UNSCEAR mean values and local data, however, the activity concentrations of ^{238}U and, mostly ^{232}Th, were higher than these references and need further investigation. The findings of this research will be complemented with the dry period (August/2023) analysis, wherein the same work will be performed to verify the influence of the seasonality on the activity concentrations of the natural radionuclides analyzed.

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