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Assessment of Natural Radionuclide Concentrations (238U, 232Th, and 40K) in Soil Samples from Different Locations in Sohag Governorate, Egypt

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Abstract: The inherent levels of radioactivity present in the environment of uranium (^{238}U), thorium (^{232}Th), and potassium (^{40}K) along with radium equivalent, absorbed dose rates, and annual effective dose equivalent were analyzed in soil samples collected from various locations within Sohag Governorate, Egypt using an N-type HPGe coaxial detector with a relative efficiency of 40% and an energy resolution of 2.0 KeV at 1.33 MeV photons of ^{60}Co. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K ranged from 9.23±0.69 Bq/kg to 20.17±1.48 Bq/kg, 12.69±0.73 Bq/kg to 23.76±1.62 Bq/kg and 178.80±3.74 Bq/kg to 373.90±7.27 Bq/kg, respectively, with an approximate mean of 16.22±1.21 Bq/kg, 18.71±1.18 Bq/kg and 311.28±5.71 Bq/kg. The calculated radium equivalent values varied from 41.14 Bq/kg to 79.23 Bq/kg with an approximate mean of 66.94 Bq/kg. Absorbed dose rates caused by γ-ray ranged from 19.60 to 37.98 nGy/h, with an approximate mean of 32.09 nGy/h. Furthermore, the annual effective dose equivalent values ranged from 0.02 mSv/year to 0.05 mSv/year, with an approximate mean of 0.04 mSv/year. These findings provide valuable insights into the levels of natural radionuclides and radiation exposure in Sohag Governorate, Egypt. The results demonstrate compliance with international safety guidelines, signifying a diminished potential for radiation hazards among the inhabitants residing in the area. The study contributes to the overall understanding of environmental radioactivity and serves as a valuable reference for future assessments and radiological protection measures.
Keywords: natural radionuclides, activity concentrations, radium equivalent, absorbed dose rates, annual effective dose equivalent, radiation exposure, radiological protection.

1. Introduction

Soil plays a crucial role in supporting plant growth and agriculture by providing nutrients, water, and habitat for microorganisms. It comes into existence via the weathering and erosion of rocks, which contribute mineral components such as sand, silt, and clay, affecting properties like texture, water retention, nutrient availability, color, and overall composition [**1**, **2**]. In the course of these mechanisms, radioactive elements have the potential to be liberated from rocks and minerals, subsequently accumulating within the soil. The dispersion of naturally occurring radioactive elements within the soil is influenced by geological processes and the composition of underlying rocks [**3**-**5**]. The main source of natural radionuclides in the soil is the decay series of uranium-238, which produces radium-226 and radon-222. Similarly, thorium-232 and its decay products, including radium-228 and radon-220, also contribute significantly to soil radioactivity. Another contributor is potassium-40, a naturally occurring radioactive isotope found in certain minerals and plants [**6**, **7**]. Human activities can influence soil radioactivity, such as industrial operations releasing radioactive materials, the use of phosphate fertilizers derived from rocks containing radionuclides, and coal-fired power plants producing fly ash with radioactive isotopes. Agricultural activities in soils with high radionuclide levels can lead to the accumulation of these contaminants in crops, posing risks to food safety and productivity. Understanding the presence and behavior of natural radionuclides in soil is crucial for assessing radiation exposure risks, implementing safety measures, and ensuring the well-being of humans and the environment. This paper aims to draw attention to the potential risks associated with the concentrations of natural radionuclides, namely ^{238}U, ^{232}Th, and ^{40}K, in soil samples collected from various locations within the Sohag governorate, situated in upper Egypt. The primary focus of the study is to evaluate the impact of these radionuclides on human health and radiation exposure. By analyzing the soil samples collected, the research seeks to assess the levels of these natural radionuclides and their potential implications for human well-being. The findings aim to provide valuable insights into the potential health risks and radiation-related effects arising from the presence of these radionuclides in the soil.

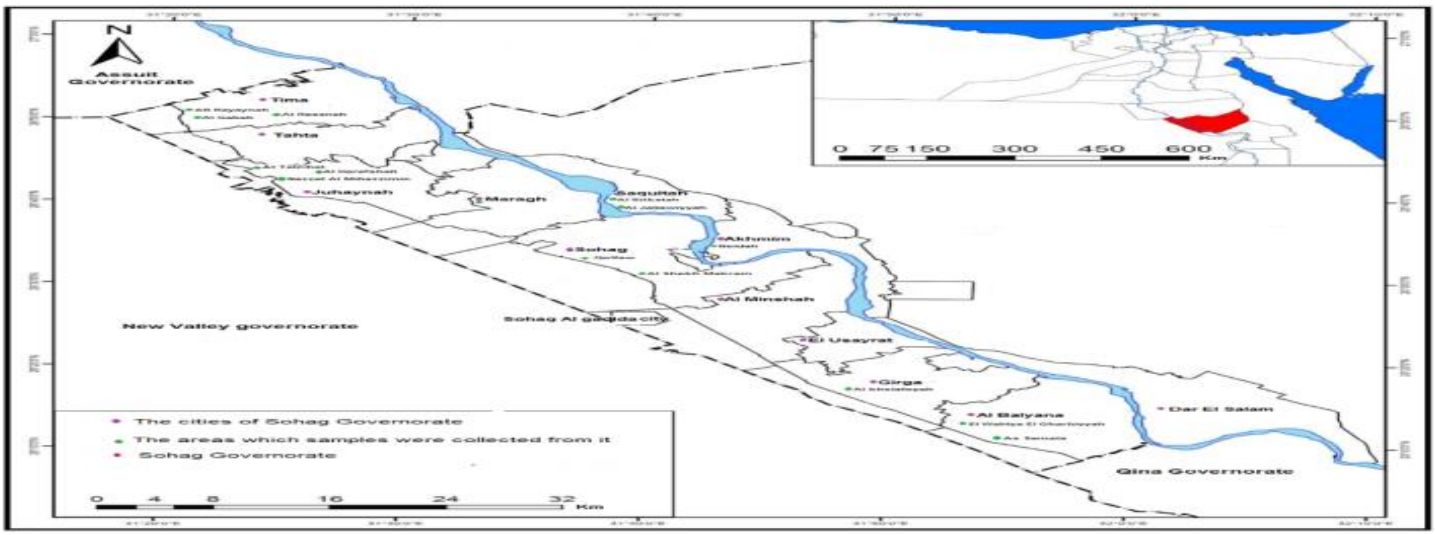

Fig. 1: Sample location map.

2. Study area

This study was carried out at Sohag Governorate, located in southern Egypt, spans across the coordinates of latitude 26°15′00″ to 26°45′00″N and longitude 31°15′00″ to 32°00 ′00″E [8]. This location exhibits a diverse array of geological features that provide valuable insights into its geological history. Positioned within the Nile Valley, Sohag is surrounded by the Eastern Desert on the east and the Western Desert on the west. The most prominent feature of the region is the Nile River, whose annual floods have deposited thick layers of alluvial soils, creating highly fertile agricultural land along its banks. These soils comprise sediments, including silt, clay, and sand, transported by the river from the Ethiopian highlands to the north. Moving eastward, the topography gradually transforms into the arid and rocky landscapes of the Eastern Desert, characterized by sandstone formations dating back to the Paleozoic Era. These formations offer glimpses into ancient, submerged environments that have since experienced weathering and erosion. On the western side of Sohag Governorate lies the Western Desert, a part of the vast Sahara Desert, showcasing extensive dunes, limestone plateaus and sporadic outcrops of sedimentary rocks. Notably, the presence of limestone and shale indicates the past existence of seas in the region, with fossil remains of marine organisms frequently discovered within these sediments. Moreover, the Western Desert features a diverse range of landforms, including mesas, wadies (dry riverbeds) and oases, formed through the intricate interplay of wind and water erosion, as well as tectonic activities, spanning millions of years [8, 10].

3. Samples preparation and Gamma spectrometric analysis

Twenty-five agricultural soil samples were gathered randomly from various locations within the Sohag governorate, each originating from a defined 0.5m × 0.5m area and extending to a depth of 20 cm. The initial stage involved removing stones and inorganic matter to ensure the soil's purity. Subsequently, the samples underwent a drying process lasting approximately three weeks, starting at room temperature and concluding in an oven set at approximately 100˚C [11]. After drying, the samples were crushed and passed through a fine mesh sieve, resulting in a fine-grained powder. These representative samples were packed into cylindrical polyethylene containers, and securely sealed with threaded lids. The weight of each sample was recorded, and adhesive tape was applied to prevent any potential leakage or tampering. The sealed containers were stored for a minimum of four weeks to achieve radioactive equilibrium [12, 13]. Subsequently, gamma spectrometry measurements were conducted at the Nuclear Research Center in Cairo, Egypt, to evaluate radiation levels. For the analysis, an N-type HPGe coaxial detector was utilized, featuring a relative efficiency of 40% and an energy resolution of 2.0 KeV at 1.33 MeV photons emitted by ^{60}Co. To ensure quality assurance, reference materials with known concentrations of natural radioactivity were employed. The precision of calibration was verified through the utilization of Lab SOCS software, which enabled a mathematical calibration of the efficiency of Ge-detectors for laboratory samples possessing comparable geometric configurations. The quantitative analysis of the spectra was performed using the CANBERRA (Genie 2000) program. Background measurements were conducted under the same conditions as the sample measurements to correct the net peak area of γ-rays emitted by the measured isotopes.

4. Activity Measurement (A_s)

Under the condition of secular equilibrium, the activity of ^{238}U was determined by analyzing specific gamma peaks emitted by ^{214}Bi (609.3, 1120.3 and 1764 keV) and ^{214}Pb (351 keV). Likewise, for the determination of the activity of ^{232}Th, gamma peaks from ^{208}Tl (583.19 and 2614.53 keV), ^{212}Pb (238.63 and 300.09 keV), ^{228}Ac (911 keV) and ^{212}Bi (727.3 keV) were utilized. The activity of ^{40}K was directly assessed based on its gamma peak at 1460.83 keV, as referenced [14-16]. To estimate the activity concentrations of the natural radionuclides ^{238}U ^{232}Th, and ^{40}K in the measured samples, equation (1) was applied [16]:

$$A_s = \frac{N_c}{M \times \varepsilon \times \eta} \text{ (Bq/kg)} \quad (1)$$

Here, A_S represents the activity concentration in Bq/kg, N_C indicates the net counting of γ-rays, M corresponds to the mass of the sample, ε represents the detector efficiency and η signifies the transition probability of γ-decay.

5. Radiological indices

5.1 Radium equivalent (Ra_{eq})

The notion of radium equivalent (Raeq) has been introduced to encompass the collective activity concentrations of ^{238}U, ^{232}Th, and ^{40}K within a sample. This accounts for both the external and the internal γ-dose stemming from radon and its progeny. This single radiological index provides a comprehensive measure of the significant activity concentration in a sample with inhomogeneous activity concentrations of these radionuclides. The mathematical expression for radium equivalent (Raeq) is given as [17, 18]:

Ra_{eq} (Bq/kg) = AU + 1.43 ATh + 0.077 AK (2)

Here, AU, ATh, and AK represent the activity concentrations of the corresponding radionuclides ^{238}U, ^{232}Th and ^{40}K, respectively, measured in becquerels per kilogram (Bq/kg).The estimation of outdoor external risk related to the exposure of terrestrial γ-rays in the air at a height of 1 meter above the ground was conducted. This assessment accounted for the presence of natural radionuclides ^{238}U, ^{232}Th, and ^{40}K, which are sparsely distributed in the soil. The calculation process for this risk evaluation is outlined as follows [18-20]:

(D_{out}) (nGy/h) = 0.462ARa + 0.621ATh + 0.0417AK (3)

where ARa represents the activity concentration of ^{238}U, ATh represents the activity concentration of ^{232}Th and AK represents the activity concentration of ^{40}K.

5.3 The annual effective dose equivalent(AEDE)

The annual effective dose equivalent (AEDE) (mSv/yr) is derived from the absorbed dose rate, incorporating a dose conversion factor of 0.7 Sv/Gy specifically for adults, as indicated by UNSCEAR 2008. Additionally, a time occupancy factor of 0.2 is taken into account. The effective dose equivalent (AEDE) is calculated using the following equations [18-20]:

Table 1: The activity concentrations in Bq/kg, radium equivalent (Ra_{eq}) in Bq/kg, absorbed dose rates (D_{out}) in nGy/h and annual effective dose equivalent (EADE) in mSv/y of ^{238}U, ^{232}Th and ^{40}K for the measured samples.

Code.	Soil Activity Concentrations (Bq/kg)			Ra_{eq} (Bq/kg)	D_{out} (nGy/h)	EADE (mSv/y)
	^{238}U	^{232}Th	^{40}K			
S_1	14.45±1.22	15.85±1.09	328.36±5.52	62.40	30.21	0.037
S_2	12.72±0,95	14.34±1.00	279.77±4.89	54.76	26.44	0.032
S_3	10.98±0.69	12.83±.91	231.18±4.27	47.12	22.68	0.028
S_4	12.64±1.02	13.90±1.01	288.58±5.14	54.73	26.50	0.032
S_5	17.48±1.33	17.92±1.62	349.15±6.48	69.98	33.76	0.041
S_6	16.36±1.23	20.80±1.30	317.86±6.03	70.58	33.73	0.041
S_7	17.40±1.20	22.77±1.21	311.25±5.56	73.92	35.16	0.043
S_8	16.71±1.22	22.77±1.17	302.86±5.55	70.10	33.41	0.041
S_9	15.69±1.41	18.07±1.33	270.31±6.24	62.34	29.74	0.036
S_{10}	19.27±1.26	20.11±073	314.56±5.61	72.25	34.51	0.042
S_{11}	14.30±1.21	17.79±1.00	267.91±5.20	60.37	28.83	0.035
S_{12}	9.23±1.08	12.69±1.27	178.80±3.74	41.14	19.60	0.024
S_{13}	17.43±1.29	21.97±1.29	340.56±5.95	75.07	35.90	0.044
S_{14}	14.57±1.14	17.66±1.12	345.74±5.84	66.44	32.11	0.039
S_{15}	20.17±1.30	21.68±1.20	364.40±6.05	79.23	37.98	0.047
S_{16}	20.10±1.48	17.65±1.32	373.90±7.27	74.10	35.82	0.044
S_{17}	19.75±1.44	23.76±1.51	325.31±6.76	78.78	37.45	0.046
S_{18}	18.34±1.43	20.72±1.40	328.25±6.55	73.24	35.03	0.043
S_{19}	16.43±1.08	19.23±.95	283.22±5.09	65.73	31.34	0.038
S_{20}	16.49±1.15	19.22±1.06	315.99±5.45	68.31	32.73	0.040
S_{21}	16.55±1.21	19.21±1.17	348.75±5.80	70.88	34.12	0.042
S_{22}	19.03±1.29	20.10±1.22	348.89±5.92	74.65	35.83	0.044
S_{23}	16.82±1.18	21.41±1.09	297.13±5.42	70.31	33.46	0.041
S_{24}	16.79±1.24	18.34±1.27	353.58±6.44	70.25	33.89	0.042
S_{25}	15.87±1.25	18.71±1.21	315.79±5.93	66.94	32.12	0.039
Max.	20.17±1.48	23.76±1.62	373.90±7.27	79.23	37.98	0.05
Min.	9.23±0.69	12.69±0.73	178.80±3.74	41.14	19.60	0.02
Average	16.22±1.21	18.71±1.18	311.28±5.71	66.94	32.09	0.04

D_{eff} (mSv/yr) = D (nGy/hr) × 8760 hr × 0.7 × (10^3 mSv/10^9 nGy) × 0.2

D_{eff} (mSv/yr) = D (nGy/hr) × 1.21 × 10^{-3} (mSv/yr) (4)

According to the findings of UNSCEAR 2000, the estimated worldwide D_{eff} resulting from natural radiation sources in areas with typical background radiation is 1 mSv/yr.

6. Results and discussions

Table 1 provides the activity concentrations in Bq/kg for the natural radionuclides ^{238}U, ^{232}Th and ^{40}K. The analysis of the data in Table 1, combined with the information presented in Figure 2, reveals that the observed activity concentrations of ^{232}Th radionuclide content in the all-samples varied within the range of 12.69±0.73 Bq/kg to 23.76±1.62 Bq/kg with an average value of 18.71±1.18 Bq/kg while the activity concentrations of ^{238}U varied within the range of 9.23±0.69 Bq/kg to 20.17±1.48 Bq/kg. Furthermore, the activity concentration of ^{40}K varied within the range of 178.80±3.74 Bq/kg to 373.90±7.27 Bq/kg. The average activity concentration for ^{238}U was determined to be 16.22±1.21 Bq/kg, while for ^{40}K, the respective average values were found to be 311.28±5.71 Bq/kg. It is noteworthy that, based on the collected data, the highest specific activity values were recorded for ^{40}K, followed by ^{232}Th and ^{238}U respectively. Importantly, all sample types investigated in this study exhibited specific activity concentrations for ^{238}U, ^{232}Th and ^{40}K that are lower than the worldwide safe limits recommended by [UNSCAER 2000]. The established limits are 35 Bq/kg for ^{238}U, 30 Bq/kg for ^{232}Th and 400 Bq/kg for ^{40}K. Table 1 provides the calculated values of radium equivalent (Ra_{eq}) in Bq/kg for the present study. Upon analyzing the data in Table 1 and referring to Figure 3, it is observed that the Ra_{eq} values ranged from 41.14 Bq/kg to 79.23 Bq/kg. The average Ra_{eq} value obtained from the study was determined to be 66.94 Bq/kg.

Importantly, the calculated average Ra_{eq} value of 66.94 Bq/kg falls below the recommended maximum value of 370 Bq/kg. This indicates that the radium equivalent levels measured in the samples examined in this study are well below the recommended threshold, suggesting a lower level of potential radiation hazard. Table 1 and Figure 4 display the calculated values of the outdoor absorbed dose rate caused by γ-ray. The analysis of the results reveals that the absorbed dose rate values varied within the range of 19.60 to 37.98 nGy/h. The average absorbed dose rate across all the measured samples was determined to be 32.09 nGy/h. Importantly, the overall findings indicate that the calculated values of the outdoor absorbed dose rate for all the samples examined in this study are lower than the global average limits recommended by UNSCEAR in 2000, which set the limit at 57 nGy/h. This indicates that the observed absorbed dose rates pose a lower level of radiation exposure compared to the established international safety standards.

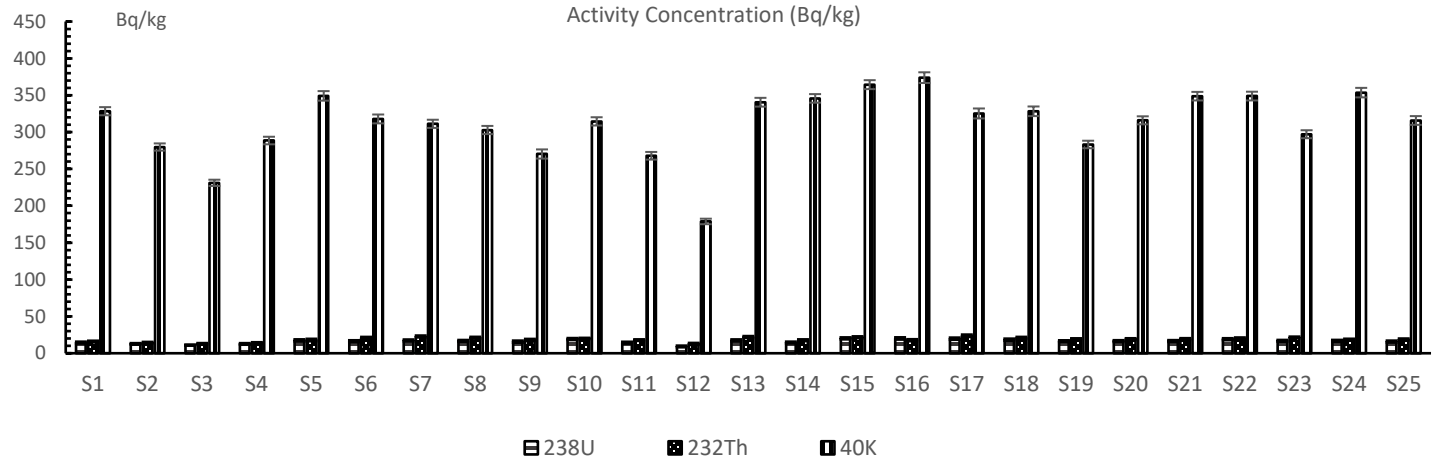

Fig. 2: The Activity concentrations in Bq/kg for all measured samples.

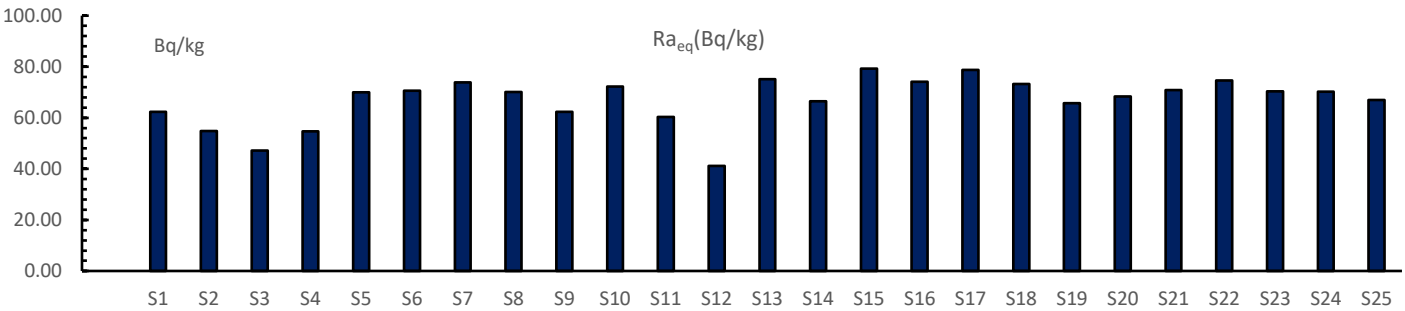

Fig. 3: The radium equivalent in Bq/kg for all measured samples.

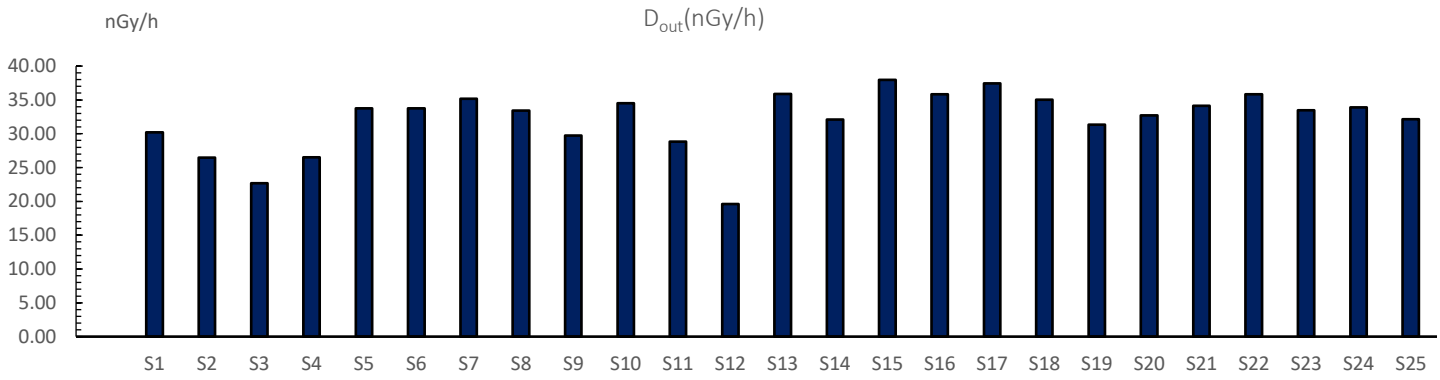

Fig. 4: The outdoor absorbed dose rate (D_{out}) in nGy/h for all measured samples.

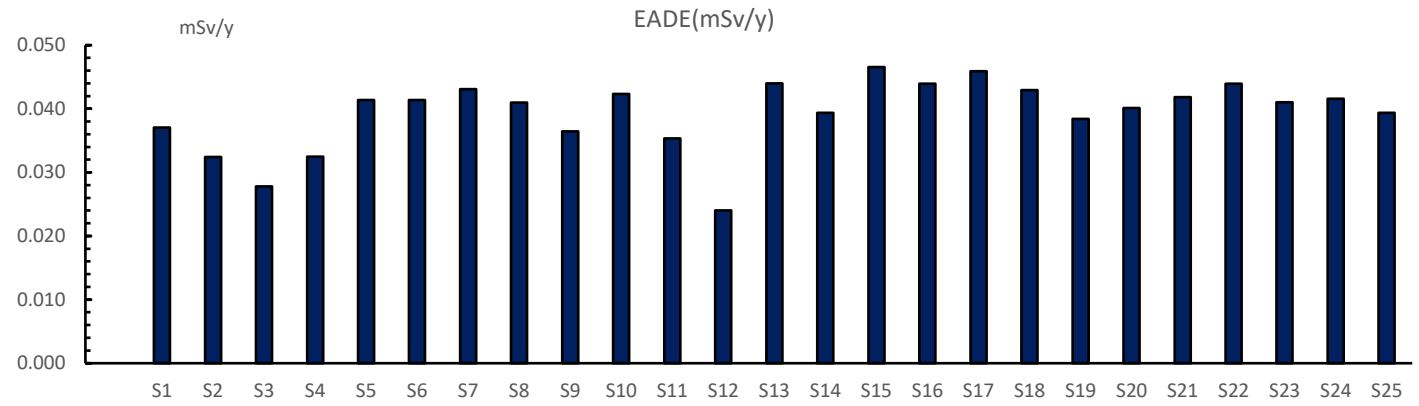

Fig. 5: The annual effective dose rate equivalent (EDRE) in mSv/year for all measured samples.

Table 1 and Figure 5 provide a comprehensive overview of the calculated values of the annual effective dose equivalent within the study samples. The results, as outlined in Table 1, indicate that the annual effective dose equivalent values exhibited a range from 0.02 mSv/year to 0.05 mSv/year, with an average value of 0.04 mSv/year. It is noteworthy that all the derived values of the annual effective dose equivalent in the study samples fall below the recommended threshold of 1 mSv/year as stipulated by the International Commission on Radiological Protection (ICRP).

7. Conclusion

Derived from the exhaustive analysis carried out, it can be deduced that the examined samples manifest activity concentrations, radium equivalent values, absorbed dose rates, and annual effective dose equivalents that consistently remain beneath the prescribed international safety thresholds. Consequently, the samples pose a negligible risk of radiation exposure and do not present any significant radiation hazard. These findings assure a high level of safety and suggest no cause for concern regarding potential radiation-related health effects.

CRediT authorship contribution statement:

The completion of this work was achieved through the collective effort of all authors. K.S.A.H. and W.M.A. played crucial roles in conceptualization, methodology development, and investigation. Additionally, they played a significant role in supervising the project. M.H. E. was responsible for the statistical analysis, ensuring accurate and rigorous analysis of collected data. M.A.E. took charge of conducting literature searches and synthesizing the findings. This involved identifying relevant studies and analyzing the similarities and differences between their results. A.A.M. played a significant role in resource collection, ensuring that all necessary information was gathered for the initial draft preparation. S.T.T. performed data curation, organizing, and managing the collected data to ensure its integrity and accessibility. All authors have read and agreed to the published version of the manuscript.

Data availability statement

The data used to support the findings of this study are available from the corresponding author upon request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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