Assessing the Radiological Risks Associated with Natural Radioactivity in Igneous Rocks of Gharyan City

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Abstract:
The purpose of this study is to assess the radiological hazards associated with natural radioactivity in the igneous rocks of Gharyan City, Libya. The research aims to assess the levels of primordial radionuclides, particularly uranium (U^{238}), thorium (Th^{232}), and potassium (K^{40}), and their potential health impacts using a High-Purity Germanium HPGe detector. Five selected sites in Gharyan were used to collect samples and prepare for analysis. The results showed activity concentrations of U^{238} ranging from 15.87 to 25.98 Bq/kg, Th^{232} from 10.48 to 37.76 Bq/kg, and K^{40} from 139.87 to 165.23 with an average of 155.59 Bq/kg. All concentrations were within permissible limits. Key radiological parameters such as radium equivalent activity, external hazard index, absorbed dose rate, and annual effective dose were calculated. The findings indicate that the radiological parameters are below safety limits set by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). In conclusion, the study contributes valuable data to the global database on radionuclide concentrations in igneous rocks and raises awareness of the potential health risks of natural radioactivity.

Keywords: *Natural Radioactivity, Radiological Risks, Igneous Rocks, and Gharyan City*

1. Introduction

Primordial radionuclides, including elements from the U^{238} and Th^{232} series, as well as K^{40} and their decay products, constitute the main source of natural radioactivity [1]. Understanding the doses from natural radiation and their health effects enhances our knowledge of radiation damage, as natural radiation is the primary source of human exposure. This knowledge facilitates the establishment of standards and regulatory measures for radiation protection. Additionally, terrestrial background radiation, which is associated with rocks, serves as the primary external source of irradiation for the human body [2]. Studying radioactivity in igneous rocks is important for several reasons. First, it aids in determining geological age, which is essential for understanding Earth's history. Additionally, it plays a crucial role in exploring mineral resources, particularly uranium and thorium, which are vital for various industrial applications. Furthermore, assessing environmental risks is another significant aspect; understanding the distribution of radioactivity helps evaluate potential risks to both humans and the environment. This study also contributes to our knowledge of geological processes, offering insights into the dynamics of Earth's crust. Moreover, it has applications in Earth Sciences that enhance our understanding of geological phenomena. Overall, the study of radioactivity in igneous rocks serves as a valuable tool for gaining a deeper understanding of the Earth and its resources. Notably, [1] found that higher radiation levels are associated with igneous rocks, whereas lower radiation levels are typical of sedimentary rocks. Information regarding the level of environmental pollution caused by radiation is crucial for the humanitarian organizations and the government in assessing and making decisions about how to manage and mitigate its effects. The findings of this study will be significant as they will enhance the global database on the concentration levels of radionuclides in igneous rocks. Additionally, this research will raise awareness of the health risks associated with these radiations.

Numerous investigations were carried out in Libya to evaluate radiation in several ecosystem systems, such as [3] [4] [5] [6] [7]. etc by following different mothods. However, the geographical region of Libya is thought to be relatively large; hence, all studies combined are insufficient. This study aims to know the natural radioactivity for igneous rocks from Gharyan city and assess the radiological hazard resulting from them, using High-Purity Germanium HPGe detector. The radium equivalent activities, the external hazard index, the absorbed dose rate, and annual effective dose have been calculated based on guidelines provided by [8].

2. Materials and methods

1) Study area and sample preparation

Gharyan city, situated on the western mountain in Libya's northwestern region, was the location of all samples in this study. According to 2021 figures, Gharyan has a population of around 187,854 and a zone without suburbs that is around 4,660 m2. The Gharyan volcanic district extends for ~3,000 km². Rock there is mostly made up of plateau lavas (basaltic andesites and transitional basalts) plus much rarer mafic alkaline lavas (hawaiites, tephrites, basanites, and alkali basalts), minor Trachytes and Phonolites [9]. The study area, from a regional perspective, encompasses basaltic volcanic rocks situated in Mizdah region, covering approximately 3,000 km². In contrast, the northern region (Gharyan) is characterized by volcanic rocks known as volonite, which comprise several outcrops, the most significant of which include Kaf Mantrous, Kaf Takout, Kaf Boghnoush, and Kaf Bourshada. Among these, Kaf Takout is considered the closest to the populated area in Gharyan (Al-Qawasim area). Regarding the geological nature of these rocks, they are volcanic rocks composed of Phonolite and Trachyte, which are part of the medium-alkaline rocks that are unsaturated with silica. They typically contain zircon and other minerals associated with uranium, thorium, and potassium. Their geological age is about 38 million years. Concerning the radioactive content of the rocks, it was observed that the radiation level in Trachyte rocks is higher than in Phonolite rocks. This was noted during field measurements in Kaf Boghnoush. This means that as the silica content increases and the crystallized minerals decrease, the levels of natural radiation also increase. As for the study site and the sampling method, it was conducted through field surveys using the GR265 device. The measurements were taken from the study area, and samples for laboratory studies were collected from points where high values were recorded. In more details, sampling of rocks samples was done from five sites were selected in study area by GR265. In order to improve statistical sensitivity, the IAEA [10] recommended taking multiple samples from each site, with three samples being collected. 15 samples were taken to the laboratory, with each sample having its own details, such as weight, location, and collection date written on them. Then each rock sample was ground to powder by crushing it into small pieces. For homogeneity, all samples were sieved through a 200 µm steel mesh, which was cleaned after each process. To obtain a representative sample of the area, all three samples from the same location were thoroughly mixed and combined into one sample; therefore, the total number of samples decreased to five rock samples. Then, each sample was dried in an oven at $105C^{o}$ to ensure that the residual moisture was completely removed. Plastic containers with Marinelli beakers were used for the packing of the samples. All samples were weighed and stored for more one month to allow daughter products to come into radioactive secular equilibrium with their parents U^{238}, Th^{232} [11].

2) Gamma-ray spectroscopy

The level of environmental radioactivity and the health risks from radiation exposure are assessed through the use of various radiological parameters. The effectiveness of measuring these parameters is dependent on the technology of the instruments used. A High-Purity Germanium HPGe detector is a device used for measuring radioactive activity, known for its high accuracy gamma rays. This detector is widely used in environmental applications, such as measuring radioactive activity in surface waters, sediments, and rocks, as it can precisely identify radiation levels. In this study, the P-type high-purity germanium HPGe detector was utilized for measuring natural radioactivity in igneous rock samples from Gharyan city. In this detector, electron-hole pairs are generated, creating an electric field in a limited space known as the "depletion region," which is devoid of particles and charges. The electron in this region is influenced by the electric field, which is governed by the applied voltage difference. The relative efficiency of the germanium detector is estimated to be around 35%, and it operates at a bias voltage of +4000 V with a resolution of 2.2 keV at the 1332 keV gamma line. To attenuate cosmic and other radiation, a lead shield was used with approximately 0.6 mm thickness.

It is necessary to calibrate the energy and determine the efficiency of the HPGe detector before measuring samples, and knowing the efficiency is very important for determining the concentrations of radioactive materials. The primary purpose of performing energy calibration of the system is to establish the relationship between the channel number in the multichannel analyzer and the peak energy of the gamma rays in the sample to be measured. This helps in identifying the linearity of the system and preparing it for sample measurement procedures. Knowing the absolute efficiency of the germanium detector is very important for calculating the concentration of radioactive activity in samples. To calibrate the efficiency of the detector, a standard source (SYR-NORM 2005) was used, which contains a set of radioactive elements with known initial activity. Additionally, background radiation is produced by cosmic radiation continuously bombarding the Earth's atmosphere and the presence of natural radioactive activity in the environment. The nature of this background radiation varies significantly depending on the size and type of the detector and the extent of shielding that can be placed around it. In this study, the background radiation spectrum was collected for 50,000 seconds without any radioactive source. In order to attain statistically smaller error levels, each sample was counted on the HPGe detector for 50,000 seconds [12]. The U^{238} activities (or Ra^{226} activities for samples assumed to be in radioactive equilibrium) were estimated from Pb^{214} (351.9, keV) and Bi^{214} (609.3, 1120.3, 1764 keV). The gamma ray energies of Pb^{212} (238 keV), Ac^{228} (911 keV) and Tl^{208} (583.2 keV) were used to estimate the concentration of Th^{232}. Whereas the activity of k^{40} has been calculated from its own gamma-ray line of energy 1460 keV [13]. The activity concentrations, calculated from the intensity of several gamma-rays emitted by a nuclide, are grouped together to produce the average activity per nuclide.

3) Calculation of the activity concentrations

The measurement of natural radioactivity due to gamma-rays from the dose rate is necessary to implement precautionary measures whenever the dose is found to be above the recommended limits. For this reason, the activity concentration (Ac) of U^{238}, Th^{232}, and k^{40} in samples was determined by the following equation:

$$Ac\ (Bq/kg) = \frac{CPS}{\varepsilon.Ir.W} \text{---} 1$$

Where Ac is the activity concentration in the sample (radioactivity unit is Becquerel (Bq) which is defined as the amount of any radioactive substances generating a decay per second), CPS is the net gamma counting rate for a peak at energy E, per second, ε is the absolute efficiency at photo peak energy, Ir is the gamma ray emission probability corresponding to the peak energy E, and W is the mass of the rock samples (Kg).

4) Calculation of the radiological effects

The radium equivalent activity is the most commonly used radiation hazard index (Raeq). It is the weighted sum of activities of U^{238}, Th^{232}, and k^{40} radionuclides which used to evaluate the actual radioactivity in the samples by single quantity. Based on [8] recommendations, it should be less than 370 Bq/kg. The equivalent activity of radium can be calculated using the following relation:

$$R_a eq = Au + 1.43 A_{Th} + 0.077 Ak \text{--------------} 2$$

Where: Au, A_{Th}, and Ak are the activity concentrations of U^{238}, Th^{232}, and k^{40} (Bq/kg) respectively.

The external hazard index (H_{ext}) that is caused by the emitted gamma rays of the samples is calculated and evaluated using the following correlation:

$$H_{ext} = \frac{Au}{370} + \frac{A_{Th}}{259} + \frac{Ak}{4810} \text{----------------------------} 3$$

Where: Au, A_{Th}, and Ak are the activity concentrations of U^{238}, Th^{232}, and k^{40} (Bq/kg) respectively. The calculated average external hazard index should be found less than one in order to keep the radiation effects without posing any significant radiological threat to the public in a study area.

There is another important indicator for calculating the effect of radioactivity in the study area, which is the absorbed dose rate. The absorbed dose rate (D^R) can be calculated by using the following relation:

$$D^R = 0.482\, Au + 0.604\, A_{Th} + 0.042\, Ak \text{ -------------} 4$$

Where: Au, A_{Th}, and Ak are the activity concentrations of U^{238}, Th^{232}, and k^{40} (Bq/kg) respectively.

The absorbed dose rate does not directly provide the radiological risk to which an individual is exposed, so annual effective dose equivalent (AEDE) is calculated. The absorbed dose can be considered in terms of the annual effective dose equivalent from indoor terrestrial gamma radiation which is converted from the absorbed dose by considering two factors, namely the outdoor occupancy factor (0.2) and the conversion coefficient from absorbed dose in air to effective dose (0.7 $Sv{\cdot}Gy^{-1}$). AEDE can be estimated using the following equation [14]:

$$AEDE = D^R\ (nGy\ h^{-1}) \times 10^{-6} \times 8760 h/y \times 0.2 \times 0.7\ SvG\ y^{-1} \text{---------} 5$$

3. Results and discussion

1) Analytical the activity concentration levels of natural radionuclides

The results indicated that the primary contribution to the background gamma radiation in rocks comes from the natural radioactive series, particularly from U^{238}, Th^{232}, and k^{40}. The results showed that there was not any artificial radioactivity in all samples. On the other said, the results show that the activity concentrations of U^{238} were ranged)15.87 to 25.98 Bq/kg (with mean 22.264 Bq/kg. This means that it is lower than the values mentioned in reports [8]. As for the concentration of Th^{232} in the samples, it ranged between (10.48 to 37.76 Bq/kg), The highest value was in sample 2 with 37.76 Bq/kg. The slight difference in radioactive concentration levels in the samples may be due to the difference in sample collection sites, the nature of the ground there as well as the ages of rock formations [14]. The average concentration of k^{40} in rock samples was the highest one with 155.59 Bq/kg (139.87 to 165.23 Bq/kg), this result is normal, as reported by many studies such as [16]. It is clear that all concentrations of U^{238}, Th^{232}, and k^{40} in the results indicate that it is within the permissible limits as shown in the table 1:

Table 1: Analytical results for the activity concentrations of U^{238}, Th^{232}, and k^{40}

Sample code	**The activity concentrations (Bq/kg)**		
	U^{238}	**Th^{232}**	**k^{40}**
Sample 1	15.87±0.79	10.48±0.52	149.89±7.49
Sample 2	22.97±1.14	37.76±1.88	161.04±8.05
Sample 3	25.98±1.29	10.48±0.52	161.96±8.09
Sample 4	24.04±1.20	28.84±1.44	165.23±8.26
Sample 5	22.46±1.12	24.71±1.23	139.87±6.99
Max	25.98±1.29	37.76±1.88	165.23±8.26
Min	15.87±0.79	10.48±0.52	139.87±6.99
Mean	22.264±1.11	22.454±1.12	155.59±7.77
St. Deviation	3.820	11.90	10.52

2) Analysis the radiological effects

Using equations 2-5, different hazards indices are calculated by using the activity concentrations of U^{238}, Th^{232}, and k^{40} as following:

a) The radium equivalent activity

As showing in fig 1, the maximum value of Raeq (Bq/kg) in rock samples is (89.37 Bq/kg) in sample 2, and the minimum value is (41.94 Bq/kg), which means that there are not any health risks associated with the study area regarding natural radioactivity.

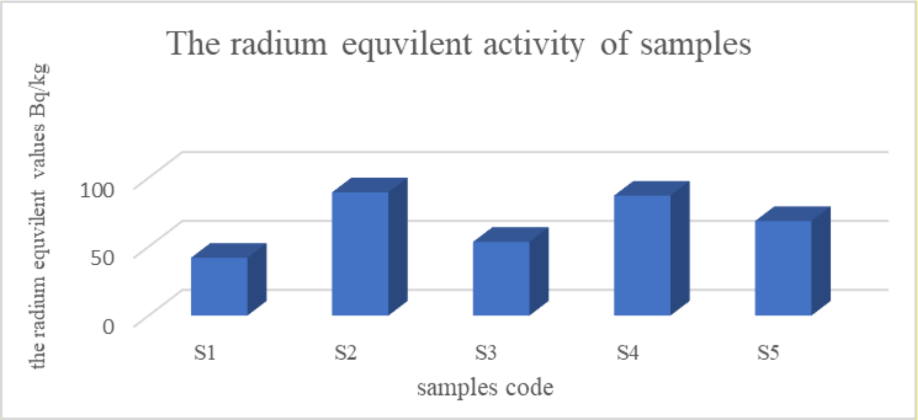

Fig 1: The radium equivalent activity of rock samples

b) The external hazard index

External exposures which occur as a result of irradiation need to determine in order to protect public. Therefore, the external hazards index for all samples was calculated, and its result is lower than the unity as it shown in the fig 2.

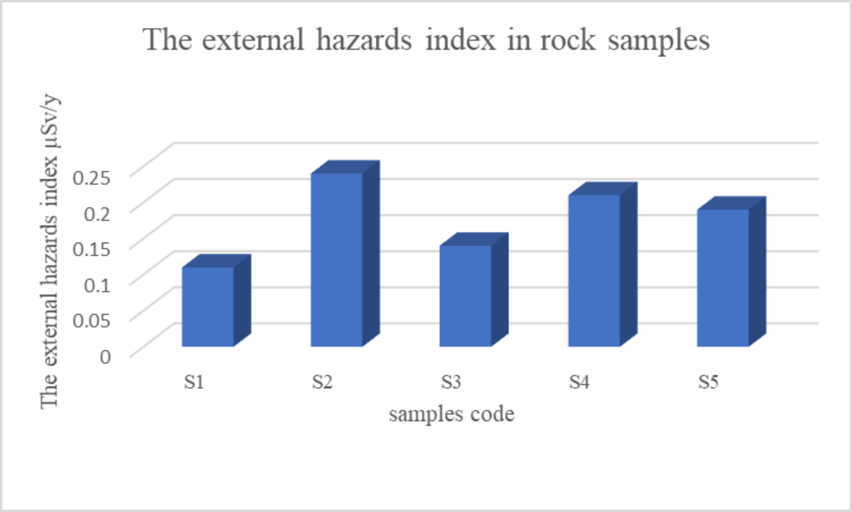

Fig 2: The external hazard index of rock samples

c) The absorbed dose rate

The relationship between the radionuclides in the environment and the radiation dose that people are exposed, so the absorbed dose should be determined to protect the public health. By the fig 3 it is clear that the absorbed dose rate is below the safe limit of (55nGy/h) for members of public.

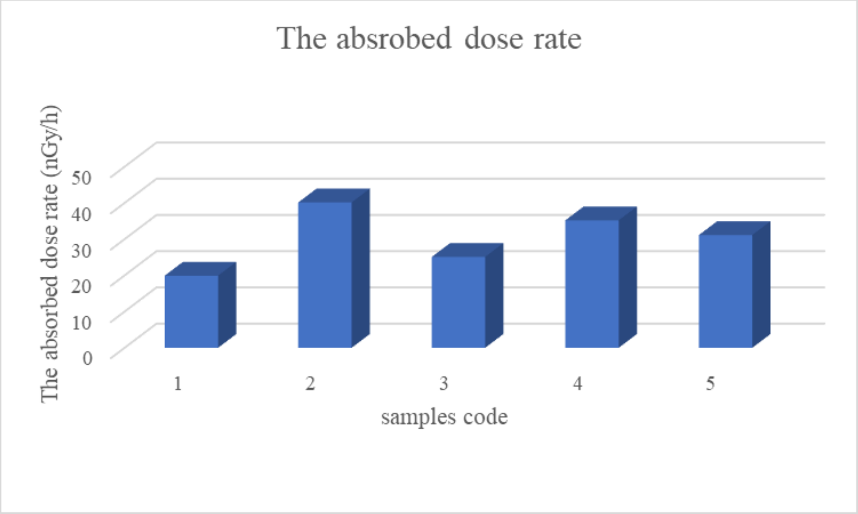

Fig 3: The absorbed dose rate from rock samples

d) The annual effective dose equivalent

The mean annual effective dose rate for the igneous rocks in this study was 0.0368 mSvy^{-1}. The data indicated that this value is well within the safety limit (1 mSv y^{-1}) as proposed by [8].

3. Conclusion

From the results it can be seen that the concentration activity of U^{238}, Th^{232}, and k^{40} for all samples collected from Gharyan city are low. All radiological parameters which have been calculated such as, radium equivalent activities, the external hazard index, the absorbed dose rate, and annual effective dose were within the safety limit as recommended by UNSCEAR. Therefore, there are no radiation risks associated with the study area at the present time. However, to protect the population in the study area and other areas, some recommendations must be followed, such as:

Continuous Monitoring of Radioactivity: It is advisable to conduct regular studies to monitor the levels of radioactivity in the igneous rocks of Gharyan to ensure continuous data regarding radiological risks.

Public Awareness: Public awareness campaigns should be organized to inform local residents about the potential risks of radioactivity and how to protect themselves, especially in areas close to sources of radioactivity.

Improving Ventilation in Buildings: Improving ventilation in buildings, particularly in basements, is recommended to reduce the accumulation of radon gas, which may seep from radioactive rocks.

Environmental Risk Assessment: Local authorities should conduct periodic environmental assessments to identify any changes in radioactivity and their impact on public health and the environment.

Building Standards Implementation: Building standards that consider the radioactivity of materials used should be adopted, especially in new construction projects.

Collaboration with Relevant Authorities: It is recommended to collaborate with national and international agencies specializing in radiation to ensure best practices in monitoring and management are followed.

Encouraging Future Research: Further research in the field of radioactivity in igneous rocks should be encouraged, including studies on the effects of various environmental factors on radiation levels.

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