Assessing environmental hazard parameters of natural radioactivity in a high background area

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Abstract: Several regions within the KSA were reported to have higher radionuclide concentrations in soil and rocks. The concentration of the radioactive radionuclides in soil and rocks depends mainly on the prevailing geochemical and geological conditions. This study aims to investigate a high background area of Natural radioactivity in Heqal village in Saudi Arabia (KSA). Fourteen samples were collected from Heqal village (9 soil samples; 5-rocks samples). Gamma spectrometry was used to measure the amounts of ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K in the collected rock and soil samples. The obtained data was also used to calculate some environmental hazard parameters, such as the absorbed gamma dose rate (AGDR), annual effective dose rate (AEDR), radium equivalent (Raeq), external and internal hazard indexes (Hex and Hin), gamma index (Iγ), alpha index (Iα), and excess lifetime cancer index (ELCR). Our findings will help decision makers and public health officials with essential information for developing strategies to reduce radiation exposure and prevent future cases of cancer.

Keywords: Natural radioactivity, Heqal village, soil, rocks, Gamma spectrometry, environmental hazard parameters.

I. Introduction

A naturally occurring radioactive material (NORM) is a component that occurs naturally and is radioactive. Among these substances are rocks, soil, water, and air. Considering the way, the Earth was formed, radionuclides are natural and cannot be removed. Radioactivity distribution and ambient radiation levels must be understood in order to calculate the effects of exposure to radiation from terrestrial and interplanetary sources. It is important to note, however, that local geological conditions often affect the concentrations of these radionuclides, even though they are widely distributed. [1]. It is impossible to avoid human exposure to ionizing radiation. Radioisotopes from cosmogenic and terrestrial sources are the primary sources of exposure. All components of the environment contain ^{238}U, ^{232}Th, and ^{40}K, including air, water, food, soil, rock, and building materials. [2]. Radiation dose attributed to these radioisotopes in construction materials is responsible for 85% of radiation exposure for the entire population in the world. Therefore, it's crucial to monitor and share information on natural radioisotope concentrations in building materials and be aware of any contamination brought on by their radioactivity in homes. [2,3]. There are three types of construction materials that can be found in the soil and rocks of the earth: structural materials, covering materials, and additive raw materials. Cement, concrete, mortar, clay bricks, and other structural materials are often used to build structures. Some building materials can have their properties changed by adding additive raw materials, such as fly ash, bauxite, and phosphogypsum, whereas some building materials can be decorated and insulated with covering materials, such as granite, ceramic, and marble. [4].

A residence's location and style, as well as its ventilation habits, are important factors affecting the radiation exposure from natural radionuclides [5]. Geochemical and geological characteristics of the study area also influence natural radionuclide activity concentrations [6]. As a result of terrestrial gamma-ray emissions, radioactivity is exposed outdoors due to the presence of radionuclides in soil and rock throughout the Earth. Due to their higher concentration of radioisotopes of thorium, uranium, and potassium, igneous rocks such as granitic rocks tend to be more radioactive than sedimentary rocks, except for some shales and some phosphate rocks that contain relatively high concentrations of these radioisotopes. [7]. Minerals and industrial products derived from granitic rocks, such as phosphate rocks utilized in industry, contain varying concentrations of terrestrial radioisotopes, depending upon their origin. Thus, it is critical to understand how terrestrial isotopes are distributed in rocks. As a result, radioactive materials containing terrestrial radioisotopes will not contaminate the environment [8].

A study is being conducted to determine environmental hazards and their impacts caused by the presence of ^{238}U, ^{232}Th, ^{226}Ra, and ^{40}K minerals in Heqal village in Saudi Arabia. The current study also maps background radiation levels for the study area, suggesting a radiological analysis. Geological processes or other factors affecting radiation levels may alter this map's background radiation levels. In addition to evaluating gamma radiation exposure caused by rocks and soil, the current study also examined thorium radiation exposure. It is possible to determine the level of radioactive threat by estimating a few of the radiological hazards' criteria.

II. **Experimental**

A. **Study area**

To the south, it borders the Emirate of Al-Baha region, and to the east, it borders the Maysan Governorate. Heqal village is southwest of Makkah Al-Mukarramah and borders the Emirate of Al-Baha. Al-Leith Governorate surrounds the emirate to the north, west, and south, and Al-Hajrah Governorate is located in the Al-Baha region to the south. It lies within the Makkah Al-Mukarramah Region and lies along the longitude 40.72449447698468 N and latitude 20.477184825945887 E (see figure 1). As part of the study area, you may also find residential areas, recreational areas, and government buildings. These sectors need to be expanded. Therefore, there is a great need to study the environment of this governorate, especially since many homes and infrastructure units are constructed over basement rocks (especially granite rocks). When cities expand, pollution from agriculture and anthropogenic activities can be distributed indiscriminately. During the study area, nearby mountains and subsurface rocks located beneath buildings could emit gamma rays, which may cause radiation pollution. It is common to see buildings constructed from granite rocks or sediments in Heqal village. It is possible to use these rocks and soil to decorate kitchens, walls, and floors. [9]

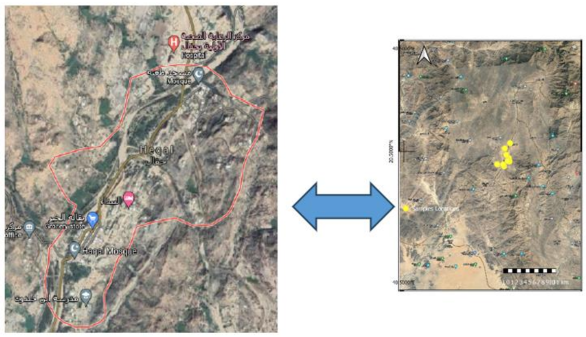

Figure 1. Location map of the study area (Heqal in southwest parts of KSA)

B. Analytical Methods

Fourteen samples were collected from Heqal village (9-soil samples; 5-rocks samples). The samples were selected depending on some factors, such as accessibility and utilization. Samples of granitic rock and soil were analyzed using γ-spectrometry with a relative efficiency of about 60%. In order to reduce the uncertainty of gamma-ray intensities, efficiency-specific radionuclide techniques were used as well as the self-absorption effects of the gamma photon [11]. A measurement of ^{238}U activity concentrations at 63.3 and 1001 keV is performed with ^{234}Th and ^{234m}Pa, respectively, from γ-lines of its daughter lines [10-12-14-15].

A specific activity concentration of ^{232}Th was determined by comparing the γ-lines energies of ^{228}Ac (338.5 keV and 911.2 keV) with those of ^{208}Tl (583 keV and 2614.4 keV). As a proxy for the ^{226}Ra activity concentration, its daughters, ^{220}Rn, ^{214}Pb, and ^{214}Bi, were determined [16]. A direct measurement of ^{40}K's activity concentration at 1460.8 keV was performed through its -line.

C. Implications of environmental hazards

In determining the potential risk to one's health, calculating the absorbed gamma dose rate is essential since it is closely related to radiological and clinical effects. Based on measured activity concentrations, ^{226}Ra, ^{232}Th, and ^{40}K dosages are calculated [17]. The gamma rate can be calculated using the equation below, the absorbed gamma dose rate, (AGDR) in nGy h−1:

$$\mathbf{AGDR = 0.461\ C_{Ra} + 0.623\ C_{Th} + 0.414\ C_K} \quad \mathbf{(1)}$$

where C_{Ra}, C_{Th}, and C_K are the activity concentrations in Bq.kg−1 of ^{226}Ra, ^{232}Th, and ^{40}K respectively. Using the observed airborne dose rate, the annual effective dose rate (AEDR) is calculated. It is essential to consider the coefficient of conversion between the rate of airborne dose absorption and the effective dose equivalent received by an adult in order to support the findings of this study [17-18]. Climate and average age of the population both affect these two variables. Annual effective dose rates are calculated using the following conversion ratio: 0.7 Sv Gy−1 between the absorbed dose in the air and the effective dose, as well as the outdoor occupancy factor of 0.2 [17,18]. A dose rate is calculated by using the following equation [19]:

$$A_{EDR}\ (mSv.yr^{-1}) = A_{GDR}\ (nGy.h^{-1}) \times 8760\ h\ yr^{-1} \times 0.7 \times (103mSv.10^{-9})\ nGy \times 0.2 = D\ (mSv.yr^{-1}) \times 1.23 \times 10^{-3} \quad (2)$$

In order to study the radiation dangers associated with 232_{Th}, 226_{Ra}, and 40_{K}, radium equivalent activity was proposed as a single quantity to reflect their various activities. It is predicted that employing 1 $Bq.kg^{-1}$ of ^{226}Ra, 0.7 $Bq.kg^{-1}$ of ^{232}Th, and 13 $Bq.kg^{-1}$ of ^{40}K will produce gamma rays at the same dose rate. It is recommended that radium equivalent (Raeq) be exposed at no more than 50 $Bq.kg^{-1}$ [19].

Using the following equation to determine the radium equivalent (Ra_{eq}):

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_{k} \quad (3)$$

where A_{Ra}, A_{Th} and A_{K} are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively in the evaluated material. For radiation risk from building material (soil and rocks) to be negligible, the maximum value of Ra_{eq} must be less than 370 Bq kg^{-1}. ^{238}U has been replaced by ^{226}Ra, a decay product of ^{238}U, as they are supposed to be in equilibrium and the contribution of the radiation hazard is from ^{226}Ra sub-series radionuclides.

Gamma radiation is evaluated for external risk using its external hazard index (H_{ex}):

$$Hex = C_{Ra}/370 + C_{Th}/259 + C_{K}/4810 \quad (4)$$

where Hex is the external hazard index and, C_{Th}, C_{Ra}, and C_{K} are the activities of ^{232}Th, ^{226}Ra, and ^{40}K in Bg.kg−1, respectively.

A radioactive progeny of ^{222}Rn can be controlled using an internal hazard index (Hin).

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_{K}/4810 \quad (5)$$

where H_{in} is the external hazard index and, C_{Th}, C_{Ra}, and C_{K} are the activities of ^{232}Th, ^{226}Ra and ^{40}K in Bg.kg−1

When used as construction materials, soil and rocks with a high radiation level may cause health problems. A gamma index below unity reduces the radiation risk and radioactivity in construction materials must be limited to 1.5 mSv. By using the following equation, the γ-index is calculated [20-21];

$$I\gamma = C_{Ra}/150 + C_{Th}/100 + C_{K}/1500 \quad (6)$$

where Iγ is γ-radiation level index and C_{Th}, C_{Ra}, and C_{K} are the activities of ^{232}Th, ^{226}Ra, and ^{40}K in Bg.kg−1

As a result of prolonged drug exposure, excess lifetime cancer risk, or ELCR, is an indicator that determines a person's likelihood to develop cancer. Estimating cancer risk using yearly effective doses at different exposure levels is possible. An estimated number of new cancers that could occur if a few people exposed to a carcinogen at a specific dose are exposed to that carcinogen.

$$ELCR = AED \times DL \times RF \quad (7)$$

where AED is the annual equivalent dose, DL is the average duration of life, which is evaluated to be 70 years, and RF is the risk factor (Sv−1), i.e., the fatal cancer risk per Sievert.

Alpha index, also known as I_α or internal health index, is derived from the equation below [22] which assesses the amount of radiation inhalated from rocks and soil due to ^{222}Rn escape:

$$\mathbf{I_\alpha = A_{Ra}/200} \quad \textbf{(8)}$$

III. Results and Discussion

3.1 Radionuclides Activity Concentrations

In Table 1, the measured activity concentrations of ^{238}U, ^{232}Th, ^{226}Ra, and ^{40}K are given for rock and soil samples collected in Bq.kg^{-1}. The concentrations of ^{238}U activity ranged from 14.46 and 45.35 Bq.kg^{-1} with an average of 28.64 Bq.kg^{-1} in the rock, in the soil the concentrations were 8.86 and 50 Bq.kg^{-1} with an average of 20.32 Bq.kg^{-1}. ^{232}Th varied between 6.43 and 50 Bq.kg−1 and averaging 23.43 Bq.kg^{-1} in the soil, but in the rock the values were 23.61 and 59.08 Bq.kg−1 with an average 41.87 Bq.kg−1. However, ^{40}K activity concentrations ranged between 198.07 and 883.56 Bq.kg−1 with an average of 554.84Bq.kg^{-1} in the soil and between 431.59 and 1703.70 Bq.kg−1 with an average of 928.84 Bq.kg−1, in the rock. Moreover, radioisotope average values (^{238}U and ^{232}Th) were concentrated within worldwide average in soil and rock accept two samples, but ^{40}K values was above the average., which is 50, 50, 50, and 500 Bq.kg−1 for, ^{232}Th, and ^{40}K, respectively [6].

Table 2 shows the basic descriptive statistics for ^{238}U, ^{232}Th, and ^{40}K amounts in the samples under investigation, including minimum, maximum, mean, standard deviation, skewness, kurtosis, and median.

Table. 1 Radionuclides activity concentrations ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K (Bq.kg−1)

Soil			
Sample No	Activity concentration, Bq/Kg		
	^{226}Ra (U-238)	^{232}Th	^{40}K
1	14.73	13.87	401.08
2	14.54	16.77	751.95
3	13.99	12.06	664.01
4	8.86	6.43	198.07
5	13.35	11.80	385.97
6	23.52	18.51	567.87
7	26.86	45.69	883.56
8	22.66	30.76	745.06
9	14.66	28.38	450.77
Permissible limit	50	50	500
Minimum	8.86	6.43	198.07
Maximum	26.86	45.69	883.56
Mean	17.02	20.47	554.84
Median	14.66	16.77	533.94
Std. deviation	5.89	12.29	207.76
Skewness	2.01	0.89	-0.06
Kurtosis	4.65	-0.44	-0.55
Rock			
Sample No	Activity concentration, Bq/Kg		
	^{226}Ra (U-238)	^{232}Th	^{40}K
1	22.93	54.61	956.33

2	26.02	59.08	1101.18
3	34.46	36.28	1703.70
4	14.46	23.61	431.59
5	45.35	35.79	451.39
Permissible limit	50	50	500
Minimum	14.46	23.61	431.59
Maximum	45.35	59.08	1703.70
Mean	28.64	41.87	928.84
Median	26.02	36.28	956.33
Std. deviation	11.76	14.66	525.85
Skewness	0.46	0.09	0.68
Kurtosis	-0.13	-1.85	-0.24

3.2 Environmental Hazard Impacts and Results

It is important to maintain compliance with absorbed gamma dose rate (AGDR) to avoid deterministic effects and to prevent potential stochastic impacts. The values were clearly above the permissible limit; 55 nGy.h−1 [23,24]. Among the AGDR values, the average value was 78.9723 nGy.h^{-1} in the soil and 423.8312 nGy.h^{-1} in the rock (Table 2).

Based on the collected samples, the annual effective dose rate for the rock varied from 0.4311 to 1.6029 mSv.y^{-1}, with an average of 0.9133 mSv.$y^{-1}$and the soil values were from 0.1941to 0.8763 mSv.y-1, with an average of 0.50 mSv.y-1 (Table 2). 40% of the collected samples fell below the permissible limit of 0.4 mg/kg/year, while 60% exceeded it [23]. R_{aeq} values for all samples are listed in Table 2. They fluctuated between 33.3081and 160.2250 Bq.kg−1 in the soil , with an average value of 25.9777 Bq.kg−1 ,in the rock the values were 81.4533 to 217.5261 Bq.kg−1 with the average value 160.0453 which is within the recommended limit of 370 Bq.kg−1for both in the soil and rock (Table 2) [24]. Mineral alteration processes affecting the studied rocks are responsible for the variation of R_{aeq} values. Table 2 shows that the average H_{ex} value of 0.4322 and 0.0702 in the rock and soil are within the permissible limit of unity, indicating that the collected rocks and soil are safely in this area. Despite a wide range of H_{in} values, the average value of 0.0791 in the soil and 0.5096 in the rock were within the unity (Table 2). The alpha index, Iα, is a measurement of the additional alpha radiation that is emitted by rock and soil when radon gas is inhaled. The alpha index considers building materials having an activity concentration of radium should be less than 200 Bq.kg−1 ; this is the recommended value [25].

Iα varied from 0.0443 to 0.1343, with an average value of 0.0244 in the soil and the average in the rock is 0.1432 (Table 2). The suggested permissible level of radium activity concentration for building materials is 100 Bq.kg−1 (Iα = 0.5), while the upper level recommended for radium activity concentration is 200 Bq.kg−1; Iα = 1 [25]. When rock and soil is used in bulk quantities as a

Table 2. Statistical parameters of environmental hazard indexes

Rock								
Parameters	AGDR (nG.h−1)	Raeq	Hex	Hin	Iγ	AED	ELCR	Iα
N	440.5148	174.6588	0.4716	0.5336	1.3365	0.9493	3.3225	0.1147
Minimum	200.0516	81.4533	0.2200	0.2590	0.6202	0.4311	1.5089	0.0723
Maximum	743.8190	217.5261	0.5874	0.6805	1.7283	1.6029	5.6102	0.2268
Mean	423.8312	160.0453	0.4322	0.5096	1.2289	0.9133	3.1967	0.1432
Median	440.5148	174.6588	0.4716	0.5336	1.3365	0.9493	3.3225	0.1301
Std. deviation	221.8259	54.2317	0.1464	0.1592	0.4404	0.4780	1.6731	0.0588
Skewness	0.5656	-0.7115	-0.7118	-1.0404	-0.4847	0.5656	0.5656	0.4611
Kurtosis	-0.5433	-0.5805	-0.5782	1.4501	-1.0209	-0.5433	-0.5433	-0.1264
Permissible limit [6]	55	370	1	1	2 to 6	0.48	0.29 x 10-3	1
Soil								
Parameters	AGDR (nG.h−1)	Raeq	Hex	Hin	Iγ	AED	ELCR	Iα
N	181.4766	65.4408	0.1767	0.2165	0.5042	0.3911	1.3688	0.0736
Minimum	90.0919	33.3081	0.0900	0.0749	0.2554	0.1941	0.6795	0.0443
Maximum	406.6401	160.2250	0.4327	0.3961	1.2250	0.8763	3.0670	0.1343
Mean	78.9723	25.9777	0.0702	0.0791	0.1996	0.1702	0.5956	0.0244
Median	257.4703	89.9518	0.2429	0.2602	0.6820	0.5548	1.9419	0.0733
Std. deviation	98.4936	36.9472	0.0998	0.1009	0.2826	0.2122	0.7429	0.0294
Skewness	-0.0858	0.5679	0.5679	-0.3117	0.4854	-0.0858	-0.0858	0.5881
Kurtosis	-0.5377	0.8224	0.8223	-0.3331	0.7119	-0.5377	-0.5377	-0.7814
Permissible limit [6]	55	370	1	1	2 to 6	0.48	0.29 x 10-3	1

construction material, it is associated with radiation risks. Rock and soil samples' gamma index (Iγ) values were calculated for rock and soil samples, the values were between 0.6202 to 1.7283 and 0.2554 to1.2250 in the rock and soil respectively. All the values of ELCR exceeded the permeation limit; these values ranged between 0.6795 to 3.0670 and 0.4311 to 1.6029 in the soil and rock respectively.

Table.3 Countries References Radionuclides activity concentrations 238U, 232Th, 226Ra and 40K (Bq.kg−1)

Countries Names, References	^{226}Ra (U-238)	^{232}Th	^{40}K
Egypt [26]	137	82	1082
Saudi Arabia [27]	54.5	43.4	677.7
Turkey [28]	45.4	82.3	931.6
Nigeria [29]	74	100	1098
China [30]	355.9	317.9	1636.5
Iran [31]	38	47	917
Italy [32]	81.33	129	1065
USA [33]	31	61	1082
Jordan [34]	41.5	58.4	897

IV. Conclusions

Throughout Haqal area in Saudi Arabia, fourteen rocks and soil samples were collected. Construction materials were made of these samples. Through gamma spectrometry, The measurements were taken ^{238}U, ^{232}Th, ^{226}Ra, and ^{40}K activity concentrations in the rock and soil samples. Based on the activity concentrations, international standards were compared (Table 3). As indicated in UNESCEAR, 2000 [6], radioisotope concentrations of ^{238}U, ^{226}Ra, ^{232}Th, and ^{40}K were within the permitted levels. Also calculated some parameters related to environmental radiologic hazards. Despite the low dose rate, absorption values ranged between 90.0919 to 406.6401 nGy.h−1 with an average value 78.9723 and 200.0516 to 743.8190 with an average value 423.8312 nGy.h−1 for the soil and rocks respectively. In addition, radioelement-bearing minerals like zircon and monazite were found in the collected rocks and soil samples, which exceeded the permissible limits. There was a wide range of annual effective dose rates in the samples collected, with an average value 0.9133 and 0.1702 mSv.y−1 in the rocks and soil respectively. Most of the collected samples were higher than the permissible limit of 0.48 mSv.y/1 in the rock, with 30% being below this limit. R_{equ} values for all studied samples fluctuated between 81.4533 and 217.5261 Bq.kg−1 with an average value of 160.0453Bq.kg−1 in the rock and 33.3081to 160.2250 with an average value of 160.0453Bq.kg−1 in the soil 25.9777 which is within the recommended limit of 370 Bq.kg−1. H_{ex} values ranged between 0.0900 to 0.4327 with an average value of 0.0702 in the soil, which is within the permissible limit (unity).the average value of rock is 0.4322 in the permissible limit (unity). As a result, the H_{in} values average value of 0.5096 and 0.0791in the rock and soil respectively within the permissible limit. Iα average values of 0.0244 and 0.1432 in the soil and rock respectively within the permissible limit. As a result, bulk quantities of these rocks are associated with radiation risks. The gamma index I_{γ} values of the samples were determined. An average of 1.2289 and 0.1996 in the rock and soil respectively were found for the gamma index. All values of ELCR were higher than the permissible limit of 0.29 × 10−3 as these values ranged between 0.6795 and 3.0670 in the soil and 1.5089 to 5.6102 in the rock. Through our approach, we encourage the better use of geological, hydrogeological, and geochemical datasets, more collecting samples, and decision-makers to guide mitigation efforts.

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