Heliyon 9 (2023) e19476

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Assessment of natural radioactivity and associated radiological risks from soils of Hakim Gara quarry sites in Ethiopia

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ARTICLE INFO

Keywords:
Radioactivity concentration
^{238}U
^{232}Th
^{40}K
Hazard indices
Gamma spectrometry

ABSTRACT

One of the ways of minimizing radiation risks to workers and the public is assessing potential sites that are suspected of producing radiation. Among such locations, quarry sites stand out because areas of granite and other rocks, especially those of uranium family potentially have high concentrations of radiation. This study was aimed to assess one such quarry sites (Hakim Gara site), located near Harar town, Harari region-Ethiopia. To assess the radiological impact of natural radioactivity of quarry activities in the study area, activity concentrations of natural radionuclides ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K in the soil samples were investigated by collecting twenty composite soil samples from different sites of the area. Measurements were carried out using high purity germanium (HPGe) Gamma Spectrometry detecting system for acquisition of data and making analysis using Genie 2000 software. From the result, mean Activity concentration of ^{238}U, ^{232}Th and ^{40}K obtained were 51.9 ± 15 Bq/kg, 68.32 ± 9.75 Bq/kg and 220.0 ± 2.0 Bq/kg, respectively. Average Activity concentration of the ^{226}Ra was 32.71 ± 2.02 Bq/kg. These values were used to calculate and estimate the radiological risks due to environmental radiation exposure contributed from the quarrying activities. The average external and internal hazard indices were 0.45 ± 0.09 mSv/y and 0.49 ± 0.23 mSv/y both of which were below the permissible limit of unity. The results obtained for ^{238}U and ^{232}Th were higher and significant from the world average which need further regulatory monitoring. The level of ^{40}K was below the world average. Hence, this research provided a foundation for future studies on subsequent investigations and to aid realistic regulatory and policy decisions.

1. Introduction

Soils and rocks are the main sources of terrestrial radiation since volcanic structures as well as rocks that are rich in phosphate, granite and salt contain natural radionuclides like ^{238}U, ^{232}Th and ^{40}K, which are the main sources of gamma radiation. In its report the United Nation Scientific Committee on Effects of Radiation (UNSCEAR) [1] points out, gamma emitting radionuclides, mainly ^{232}Th,

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https://doi.org/10.1016/j.heliyon.2023.e19476
Received 21 March 2023; Received in revised form 28 July 2023; Accepted 23 August 2023

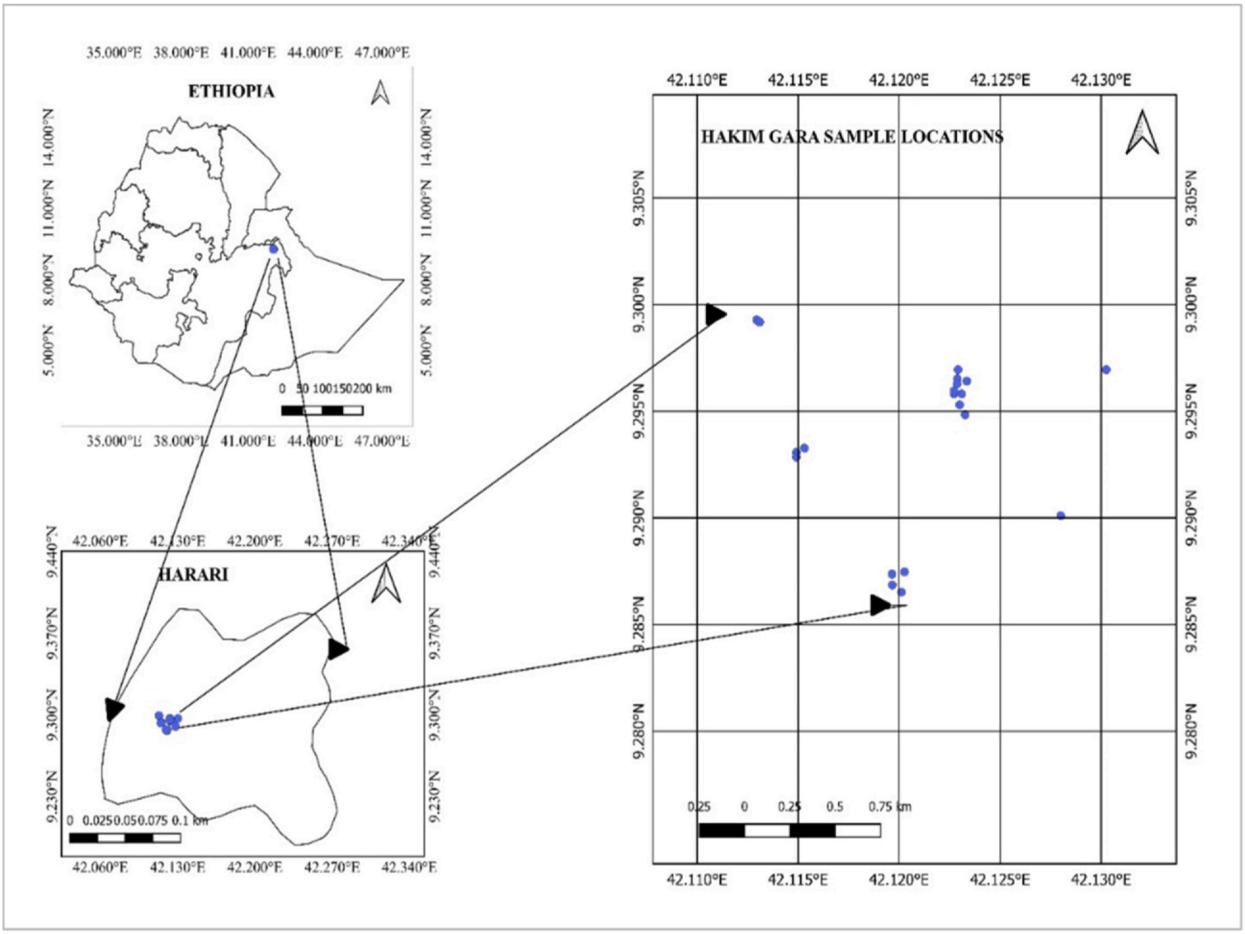

Fig. 1. The study area locating map.

^{238}U, and ^{40}K families present in trace amounts in the soil are the main contributors to external exposures. ^{226}Ra accounts for 98% of ^{238}U decay subseries and it is sometimes considered instead of ^{238}U [2].

Ionizing radiation has short-term and long-term effects on health particularly associated with the Naturally Occurring Radionuclides (NOR). The short-term effect should be prevented while the long-term effect should be reduced to an acceptable level by monitoring the quarry sites. Direct dose rate readings or analyses based on measured values of concentrations of radionuclides in sample soil provide information on outdoor exposure. The primary gamma radiation producers are these radioactive elements [3].

In the technical report by the International Atomic Energy Agency (IAEA), the distribution of radionuclides in the geosphere depends on the distribution of the geological media from which they are derived and the processes which concentrate them at a specific location in specific media [4]. According to the IAEA Safety Glossary [5], Naturally Occurring Radioactive Material (NORM) is a radioactive material containing no significant amounts of radionuclides other than naturally occurring radionuclides, where the exact definition of significant amounts of naturally occurring radionuclides would be a regulatory decision. NORMs are found in oil drilling, mining, water production, quarrying sites; etc. Depending on the amount of concentration, NORM can pose health hazards to the people living near or within quarrying sites. Hence determining and assessing the types, spatial distributions and concentrations of the radionuclides in rocks and soil helps to estimate the radiological impact on the public and workers who might be exposed to gamma radiation from terrestrial natural radionuclides. According to the Environmental Protection Authority guidance (EPA's Memo) [6], radionuclides found in all types of soils, rocks and materials of some geographic areas with granites and phosphate limestone may contain a number of radioactive minerals in their rocks matrix that can have concentrations much higher than background levels. In its survey result on NORM associated with mining, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) [7] indicated that most mining operations sampled did not have issues related to elevated levels of NORM but, the radiation results from quarry product samples were found to be higher than mines. That means, quarry sites stand out when it comes to radiation hazard because areas of granite and other rocks, especially those of uranium family potentially have high concentrations of radiations.

One of the manifestations of such activities is the increasing demand of construction activities for infrastructures, most of which need raw materials as inputs. The raw materials, are excavated and transported from quarry sites. Such excavation or quarrying activities might pose radiological pollution or health risk from the naturally occurring radionuclides underground.

The requirement of construction materials increases along with the developing urbanization. Despite the most of quarries are established in rural or semi-rural areas, their locations remain in or close to the urban areas in parallel with the expansion of residential areas in proportion to the rate of urbanization. Continuing population growth, social, industrial and economic developments require more construction materials [8]. Urban expansion and increase in the spread of quarry brought many environmental problems [9]. And also abandoned quarries bring along damages resulting in safety problems and inverse environmental impacts [8].

On Hakim Gara (Achim mountain), about 2 km South of Harar, a limestone quarry was opened around 1962 [10]. In the past, the quarry site used to be a bit far from the town, but currently it is very close to the Harar town since both the town and the quarry sites are expanded. As the resource (the quantity of quarried stones) dwindles, the quarry sites are also expanding in all directions (in search of more resource), including expansion to the suburbs of cities/towns.

There was no radiation hazard study done on this site so far because of lack of awareness of the risks associated with radiation. The purpose of the study was to investigate and determine the activity concentrations of the long-lived radionuclides and assessing the associated radiological risks. This study is therefore aimed to focus on this quarry site first, to assess the levels of radiations emitted mainly from ^{238}U, ^{232}Th and ^{40}K sources that could elevate the background radiation and secondly, to recommend monitoring the quarry site in order to keep the level of exposure to an acceptable level.

2. Materials and methods

2.1. Description of the study area

Hakim Gara is situated between 9.284° N and 9.286° N and between 42.102° E and 42.118° E in the Eastern part of Ethiopia, near the ancient UNESCO registered Harar (Jugel) town, the capital of Harari region, shown in Fig. 1, which is about 520 km from Addis Ababa and the selected quarry activity sites are located about 5 km from the town and can be accessed through dry weather gravel road. The locations are at altitudes ranging from 1991 *m* to 2226 *m* a.s.l (above sea level). According to Bussa and Belayneh, the mean annual daily temperature in the area is about 19.3 °C and the mean values of minimum and maximum daily temperatures are 13.1 °C and 25.3 °C, respectively. The area has two rainy seasons with short rainy season between February and April while the long rainy season is from June to August with annual average rainfall 669 mm [11].

According to the study by Walle et al., large limestone deposits formed the geology of the Harar Hakim Gara area [12]. The limestone forms the hills of Hakim Gara and it is considered to have large potential deposits that are easily accessible. The limestones are extracted in commercial-sized blocks. Mining Companies and the Marble Industry are among others operating quarrying activities in the area.

2.2. Sampling and sample preparation

Sampling was carried out in two groups or sites. Grouping was necessary since the sites varied in longitude and altitude. Group 1 sample locations (TS1, TS2, TS3, TS5, TS9, TS16, TS17, TS18, TS20) lie between 42.1129° E and 42.1202° E with altitudes ranging from 2046 *m* to 2126 *m* and found along Hakim Road to the South of Haji Ture Square that leads to the other side of mount Hakim Gara. Group 2 sample location (TS4, TS6, TS7, TS8, TS10, TS11, TS12, TS13, TS14, TS15, TS19) lies between 42.4227 E and 42.1302 E and the altitudes range from 1991 *m* to 2045 *m* and found at the back of Harar Nur mosque. Group 1 sample locations are at a higher altitude relative to Group 2 sample locations. A total of 20 samples (nine from Group 1 and eleven from Group 2) were collected. Differences in sample sizes occurred between the two groups because of topographical challenges (steep hill not suitable for digging) to collect samples from some locations of Group 1 site.

After removing the possible contamination on the top surface of undisturbed soil, soil samples were collected from surfaces at depths of 5–15 cm. Thereafter, organic materials and roots were separated from the samples and then mixed and transferred to labeled air-tightened polythene bags. The samples were transported to Ghana Radiation Protection Institute (RPI) laboratory for sample source preparation, measurements and analysis.

In the laboratory, the soil samples were air-dried for 3–5 days, and further oven dried between 0.5 and 2 h s at 60–70 °C until all moisture was completely lost. The samples were grinded using metal balls mill and then sieved with 450 μm mesh wire for homogenization. The homogenized soil samples were transferred to counting containers and measured with electronic balance of sensitivity 0.01 mg, labeled and sealed with paper tape to make it air-tight to avoid random escape of ^{222}Rn [13]. The samples (with weights ranging from 202 g to 245 g) were placed on the shelf for four weeks to ensure secular equilibrium. The geometry of the plastic containers used in this study have bottom diameter 7.5 cm, top diameter 8.3 cm and height 3.5 cm.

2.3. Measurements and data collection

Before collecting the samples from selected sites, the terrestrial background level of ionizing radiation was measured using a portable RADIGM 2000 detector (manufactured by CANBERA) five times on each sampling location at 1 *m* height above the ground and the averages were recorded. Geographic locations measurements were taken using Garmin GPS (model 72H).

Gamma radiation in the samples were measured using High-resolution gamma spectrometry with a p-type Extended Range Germanium coaxial detector (Model GX4018 with Carbon-Epoxy window) with a relative efficiency of 40% and an energy resolution of 2.0 keV for gamma-ray energy of 1332 keV of ^{60}Co. The detector was coupled and connected to a Multi-Channel Analyzer (MCA) and desktop computer. The semiconductor detector was mounted within a cylindrical lead shield of 5 cm thickness, 24 cm inner diameter and 60 cm height. The leaded shield is also lined with copper, cadmium and Plexiglas layers of each 3 mm thick that are lining the inner part of the leaded shield [13,14]. The identification of individual radionuclides was performed using their characteristic gamma-ray energies and the quantitative analysis of radionuclides was performed using the Genie 2000 gamma acquisition and analysis software. Background spectra were acquired and used to correct the net peak area of gamma rays of the measured isotopes. The background spectrum was also used to determine the minimum detectable activities of ^{226}Ra (0.33 Bq), ^{232}Th (0.34 Bq), ^{40}K (1.62 Bq) and ^{238}U (0.35Bq) at the 95% confidence level.

The activity concentrations of ^{226}Ra were determined using the γ-ray emissions and the respective γ-yield of ^{214}Pb at 351.9 keV (35.8%) and ^{214}Bi at 609.3 keV (44.8%). The ^{232}Th activity concentrations were determined through the gamma emissions of ^{228}Ac at 911 keV (26.6%), and ^{212}Pb at 238.6 keV (43.3%) and ^{208}Tl at 583 keV (30.1%) and 2614.7 keV (35.3%) taking into consideration a branching ratio of 33.7% from ^{212}Bi towards ^{208}Tl. The ^{40}K activity concentration was determined directly from its emission line at 1460.8 keV (10.7%). Lastly, the ^{238}U activity concentrations were determined through the gamma-ray emission of its daughter ^{234}Th at 63.29 keV (4.8%). The intensities and energies of the various radionuclides were all acquired from a well-recognized library.

Prior to counting gamma radiation in the samples, standard reference materials [IAEA-RGU-1(U ore), IAEA-RGTh-1 (Th ore) and IAEA-RGK-1(K ore)] having similar densities with the measured soil samples after pulverization, were prepared in similar geometry containers to calibrate the efficiency of the measuring system. A multi-gamma certified cocktail standard (^{241}Am, ^{109}Cd, ^{57}Co, ^{139}Ce, ^{113}Sn, ^{85}Sr, ^{137}Cs, ^{60}Co and ^{88}Y) in a 1 L Marinelli beaker was used for energy calibration of the gamma system. After four weeks of secular equilibrium, each soil sample in the container was placed into the shielded HPGe detector and the radionuclides in the soil sample were counted. By setting 10 h of counting time to each sample, the spectral data were acquired.

2.4. Data analysis

2.4.1. Calculation of activity concentration

Natural radionuclides' activity concentration, C, were calculated (in Bq/kg) for the different gamma transitions using Eq. (1) [15].

$$C = \frac{\frac{N_s}{t_s} - \frac{N_b}{t_b}}{\varepsilon(E_i) I_i m_s} = \frac{N_{cps}}{\varepsilon(E_i) I_i m_s} \tag{1}$$

Where; N_{cps} is the net counts per second, N_s is net the radionuclide counts in the samples, t_s is counting time for the sample, N_b is the net radionuclide counts in the background, t_b is the background measuring time, $\varepsilon(E_i)$ is the peak efficiency of the detector at energy E_i, I_i is the probability of gamma emission and m_s is mass of the sample.

2.4.2. External hazard index (H_{ex})

Cosmic and terrestrial radiations are sources of external radiation. Gamma radiation emitted from the terrestrial like soil, rock and building materials are contributing to the radiation dose. The contribution is mainly dependent on the concentration of the radionuclide's found in the ground [16]. The External (H_{ex}) hazard indices of each sample are calculated using Eq. (2) [17–20].

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{2}$$

2.4.3. Internal hazard index (H_{in})

Excluding radon, the cause of internal radiation dose in a body is when radionuclides are incorporated into it by inhalation, drinking, eating and absorption. The internal radiation dose arises mainly from the β-decay of ^{40}K because the electrons deposited all their energy in the body, while the γ-radiation left the body without being attenuated. The intake of radionuclides through inhalation should be considered while the particulate matters (PM) in air containing enhanced content of radionuclides [16] are inhaled. The internal (H_{in}) hazard indices are calculated using Eq. (3) [17,19,20].

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{3}$$

2.4.4. Absorbed gamma dose rate (D_γ)

Assessment of radiological impact of radionuclides in the measured soil samples, needed the estimation of γ-radiation doses by applying Eq. (4) [1,18], and [21].

$$D_\gamma = (0.462 A_u + 0.604 A_{Th} + 0.0417 A_K) nGyh^{-1} \tag{4}$$

Where: D_γ is absorbed gamma dose rates, A_U, A_{Th}, and A_K are activity concentrations of ^{238}U, ^{232}Th, and ^{40}K, respectively.

2.4.5. Annual effective dose (AED)

Estimation of the annual effective dose received by a person can be calculated from the absorbed dose rate by applying Eq. (5) [17].

$$AED\left(\frac{mSv}{y}\right) = D_\gamma (DF)(OF) T 10^{-3} \tag{5}$$

Table 1
Sample location in Degree decimal and average radionuclides concentration in Bq/kg.

Sample ID	Longitude (E)	Latitude (N)	^{238}U	^{232}Th	^{40}K	^{226}Ra
TS1	9.2992	42.1129	14.9 ± 4.3	94.7 ± 12.4	335.4 ± 89	22.8 ± 3.3
TS2	9.2874	42.1202	17.3 ± 5.4	89.9 ± 10.6	236 ± 68.3	23.1 ± 6.5
TS3	9.2991	42.1131	57.4 ± 16	56.3 ± 6.9	318.7 ± 85.8	20.3 ± 0.5
TS4	9.2953	42.123	39.8 ± 11.5	20 ± 4.4	171.2 ± 47.8	39.8 ± 11.5
TS5	9.2930	42.1149	117 ± 34.6	114.5 ± 17.3	225.8 ± 64	47.3 ± 3.5
TS6	9.2969	42.1302	29.8 ± 8.6	27.2 ± 6	131.3 ± 36.6	9.7 ± 2
TS7	9.2958	42.1231	89.2 ± 25.7	80.7 ± 9.5	287.9 ± 80.5	44.1 ± 1.5
TS8	9.2965	42.1228	50 ± 14.7	50.1 ± 5.8	175.8 ± 50.2	30.4 ± 0.1
TS9	9.2865	42.1201	95 ± 26.6	95.7 ± 13.5	206.9 ± 56.3	34.5 ± 0.1
TS10	9.2962	42.1228	88.3 ± 26.4	83 ± 10.4	255.5 ± 74.7	40 ± 0
TS11	9.2969	42.1229	10.5 ± 3.4	40.4 ± 6.2	144.7 ± 42.4	23.7 ± 1.1
TS12	9.2948	42.1232	67.9 ± 21.2	57.3 ± 9.1	237.1 ± 72.3	39.1 ± 0.3
TS13	9.2958	42.1227	10.9 ± 3.6	25.7 ± 5	168.9 ± 50.1	22.2 ± 0.2
TS14	9.2964	42.1233	14.9 ± 4.6	54.3 ± 8.1	245.7 ± 71.2	36.8 ± 0.8
TS15	9.2901	42.128	10.6 ± 3.3	34.2 ± 5	224.3 ± 63.3	28.1 ± 0.7
TS16	9.2932	42.1153	105.8 ± 32	120.3 ± 19	232 ± 67.3	40.2 ± 3.7
TS17	9.2928	42.1149	14.6 ± 4.4	93.6 ± 12.4	206.6 ± 56.8	50.5 ± 0.5
TS18	9.2868	42.1196	119.2 ± 32.1	98.5 ± 14.8	190.3 ± 49	45.5 ± 3.4
TS19	9.2959	42.1227	11 ± 3.2	39 ± 6.5	172.8 ± 46.6	27.7 ± 0.6
TS20	9.2873	42.1196	73.9 ± 22.2	91 ± 12.1	232.2 ± 67.9	28.4 ± 0.1
Minimum	–	–	10.5 ± 3.	20 ± 4.4	131.3 ± 36.6	9.7 ± 0.0
Maximum	–	–	119.2 ± 34.6	120.3 ± 19	335.4 ± 89	50.5 ± 11.5
Average	–	–	51.9 ± 15.	68.32 ± 9.75	220.0 ± 2.0	32.71 ± 2.02
World avg.[a] [26]	–	–	33	45	420	32
IAEA [27]			66	37		

[a] The world averages are the population weighted values.

Where: D_γ is absorbed dose rate in μSv/h, T is the total number of hours annually (8760 h), DF is the conversion factor of 0.7 Sv Gy^{-1} and *OF* is the *occupancy factor (0.2 for outdoor and 0.8 for indoor)* [1]. For the worker 2000 working hours per year, according to the international Labor Organization (ILO), is considered and used for calculation of annual effective dose for quarry workers.

2.4.6. Excess lifetime cancer risk (ELCR)

ELCR is a tool used for assessing and predicting the probability of risk of developing cancer from low-dose radiation exposure throughout the lifetime of a person [22–24]. Equation (6) is applied to estimate and assess the cancer risk of the public and workers as

$$ELCR = (AED)(DL)(RF) \tag{6}$$

Where: AED is annual effective dose, DL is the average duration of lifetime of a person is 70 years. RF is the cancer risk factor. Low-dose background radiation is a considered as a cause of long-term effects on public and workers [25].

3. Results and discussion

Results of radioactivity concentration for ^{238}U, ^{232}Th and ^{40}K, are presented in Table 1., ranging from 10.5 ± 3.2 Bq/kg to 119.2 ± 34.6 Bq/kg, 20 ± 4.4 Bq/kg to 120.3 ± 19 Bq/kg and from 131.3 ± 36.6 Bq/kg to 335.4 ± 89 Bq/kg for the three radionuclides, respectively. The average activity concentrations obtained are 51.9 ± 15.19 Bq/kg, 68.32 ± 9.75 Bq/kg and 220.0 ± 62.0 Bq/kg for ^{238}U, ^{232}Th and ^{40}K, respectively.

Relatively elevated activity concentrations were observed in this study compared to the world averages by UNSCEAR in 11 locations for ^{238}U and in 14 locations for ^{232}Th. The ^{40}K activity concentration measured for all samples were below the worldwide average values. The average values for ^{238}U of about 52 Bq/kg is higher than the world average, but close to the average value for soils (66 Bq/kg) according to the IAEA technical reports series 419 [4]. The average value obtained for ^{232}Th, which is 68 Bq/kg is higher than the world average of 45 Bq/kg. That of ^{40}K of 220 Bq/kg is about half of the average values of 420 Bq/kg. The higher activity concentrations obtained for ^{238}U and ^{232}Th indicate the high radioactivity concentrations in the limestone of the area. Though mean activity concentrations of ^{238}U and ^{232}Th radionuclides in the soil samples are above the world average, the measured values are far below the IAEA recommended exemption levels of 1000 Bq/kg for ^{238}U and ^{232}Th, and 10,000 Bq/kg for ^{40}K in soil [27].

The results from each sample point were analyzed in two groups based on their longitude and altitude positions. Comparing results of the two group shows that average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in group 1 are found to be 68.34, 94.94 and 242.7, respectively, while in Group 2 these values are 38.44, 46.54 and 201.38, respectively. In both groups average activity concentrations of ^{40}K are much lower than the world average value whereas the ^{238}U and ^{232}Th values are found high.

ANOVA comparison between the two groups shows p-value of 0.0931 which is greater than 0.05 for ^{238}U. This value indicates statistically significant difference between the two groups. The box plot (Fig. 2) depicts more variability among the group one (Gp 1) replication ns than those of group 2 (Gp2).

In the case of ^{232}Th ANOVA comparison between the two groups shows p-value of 3.92×10^{-5} which is much less than 0.05. This

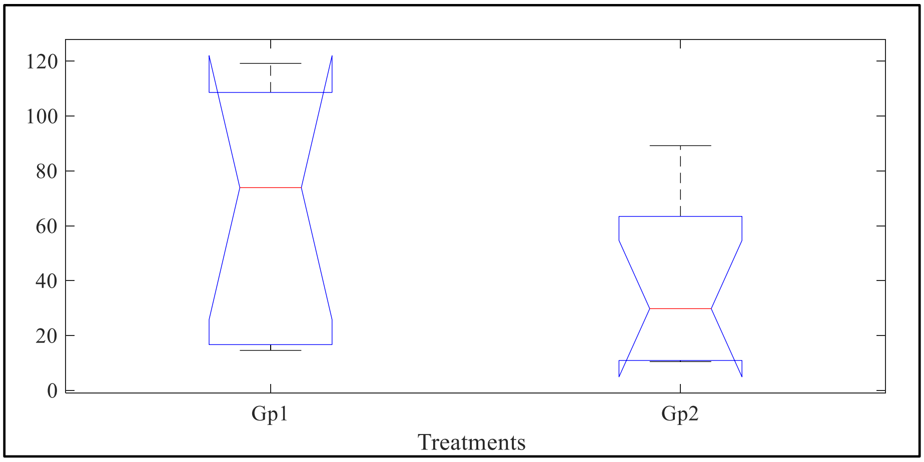

Fig. 2. Box plots of Gp1 and Gp2 shown for ^{238}U.

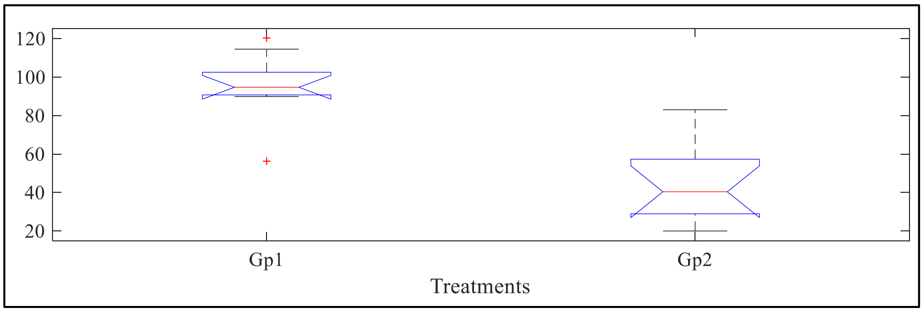

Fig. 3. Box plot of ^{232}Th.

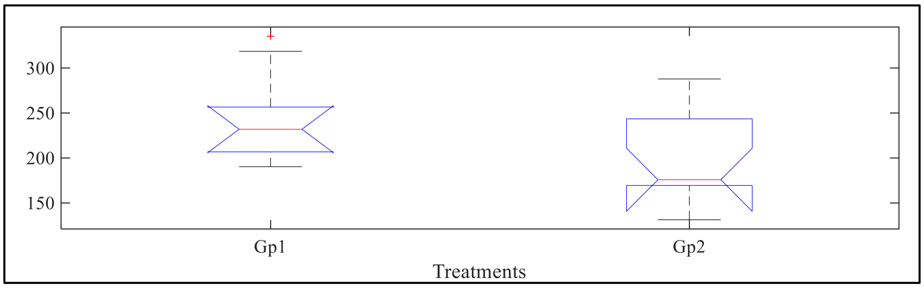

Fig. 4. Box plot of ^{40}K.

value indicates no statistically significant difference between the two groups. The box plot (Fig. 3) depicts more variability among the group 2 (Gp 2) replications than those of group 1 (Gp1).

ANOVA comparison between the two groups of ^{40}K shows p-value of 0.086 which is greater than 0.05 and indicates statistically significant difference between the two groups. The box plot (Fig. 4) depicts more variability among the group 2 (Gp 2) replications than those of group 1 (Gp1).

The other values evaluated in this study are radiological risk parameters (H_{ex} and H_{in}) for individual and group locations. As shown in Table 2, results of average values of the indices of the individual location were found to be below the value recommended, 1 mSv/y. In all sampling locations the obtained average values of AEDs were found to be elevated with respect to the worldwide average value of 0.07 mSv/y [26] for outdoor. The ELCR values were also found to be higher than the world average of 0.29×10^{-3}, which is recommended by UNSCEAR [26].

All in all, there is variation in ^{238}U and ^{40}K in terms of altitude/longitudinal difference. Since Group1 is at a slightly higher altitude, it has not been exposed very much compared to Group 2 that has been exposed over a longer time. When comparing again averages of the two groups with respective to the world average values, the values of ^{238}U and ^{232}Th in Group 1 are more than twice those of the

Table 2
Radiological risk assessment parameters on individual sample locations.

Sample ID	H_{ex}	H_{in}	D_{γ}	AED (mSv/y) Public	AED (mSv/y) Workers	ELCR ($x10^{-3}$) Public	ELCR ($x10^{-3}$) workers
TS1	0.48 ± 0.08	0.56 ± 0.19	81.7 ± 12.73	0.10 ± 0.02	0.11 ± 0.02	0.35 ± 0.06	0.32 ± 0.05
TS2	0.44 ± 0.07	0.52 ± 0.18	74.81 ± 12.25	0.09 ± 0.02	0.10 ± 0.02	0.32 ± 0.05	0.29 ± 0.05
TS3	0.44 ± 0.09	0.39 ± 0.15	56.67 ± 7.98	0.07 ± 0.01	0.08 ± 0.01	0.24 ± 0.03	0.22 ± 0.03
TS4	0.22 ± 0.06	0.33 ± 0.24	37.61 ± 9.96	0.05 ± 0.01	0.05 ± 0.01	0.16 ± 0.04	0.15 ± 0.04
TS5	0.80 ± 0.17	0.75 ± 0.34	100.43 ± 14.74	0.12 ± 0.02	0.14 ± 0.02	0.43 ± 0.06	0.39 ± 0.06
TS6	0.21 ± 0.05	0.19 ± 0.08	26.39 ± 6.07	0.03 ± 0.01	0.04 ± 0.01	0.11 ± 0.03	0.10 ± 0.02
TS7	0.61 ± 0.12	0.61 ± 0.29	81.12 ± 9.79	0.10 ± 0.01	0.11 ± 0.01	0.35 ± 0.04	0.32 ± 0.04
TS8	0.37 ± 0.07	0.39 ± 0.2	51.64 ± 5.64	0.10 ± 0.01	0.07 ± 0.01	0.22 ± 0.02	0.20 ± 0.02
TS9	0.67 ± 0.14	0.6 ± 0.25	82.37 ± 10.55	0.10 ± 0.01	0.12 ± 0.01	0.35 ± 0.05	0.32 ± 0.04
TS10	0.61 ± 0.13	0.6 ± 0.27	79.27 ± 9.40	0.10 ± 0.01	0.11 ± 0.01	0.34 ± 0.04	0.31 ± 0.04
TS11	0.21 ± 0.04	0.31 ± 0.16	41.39 ± 6.02	0.05 ± 0.01	0.06 ± 0.01	0.18 ± 0.03	0.16 ± 0.02
TS12	0.45 ± 0.11	0.48 ± 0.26	62.56 ± 8.65	0.10 ± 0.01	0.09 ± 0.01	0.27 ± 0.04	0.25 ± 0.03
TS13	0.16 ± 0.04	0.25 ± 0.15	32.82 ± 5.20	0.04 ± 0.01	0.05 ± 0.01	0.14 ± 0.02	0.13 ± 0.02
TS14	0.30 ± 0.06	0.46 ± 0.25	60.05 ± 8.23	0.10 ± 0.01	0.08 ± 0.01	0.26 ± 0.04	0.24 ± 0.03
TS15	0.21 ± 0.04	0.33 ± 0.18	42.99 ± 5.98	0.10 ± 0.01	0.06 ± 0.01	0.19 ± 0.03	0.17 ± 0.02
TS16	0.8 ± 0.17	0.73 ± 0.31	100.91 ± 15.99	0.12 ± 0.02	0.14 ± 0.02	0.43 ± 0.07	0.40 ± 0.06
TS17	0.44 ± 0.07	0.68 ± 0.33	88.48 ± 10.09	0.11 ± 0.01	0.12 ± 0.01	0.38 ± 0.04	0.35 ± 0.04
TS18	0.74 ± 0.15	0.67 ± 0.31	88.45 ± 12.55	0.11 ± 0.02	0.12 ± 0.02	0.38 ± 0.05	0.35 ± 0.05
TS19	0.22 ± 0.04	0.34 ± 0.19	43.56 ± 6.15	0.05 ± 0.01	0.06 ± 0.01	0.19 ± 0.03	0.17 ± 0.02
TS20	0.6 ± 0.12	0.55 ± 0.21	77.77 ± 10.19	0.10 ± 0.01	0.11 ± 0.01	0.33 ± 0.04	0.30 ± 0.04
Average	0.44 ± 0.09	0.49 ± 0.23	65.55 ± 9.41	0.08 ± 0.01	0.09 ± 0.01	0.28 ± 0.04	0.26 ± 0.04
Maximum	0.80 ± 0.17	0.75 ± 0.34	100.91 ± 15.99	0.12 ± 0.02	0.14 ± 0.01	0.43 ± 0.07	0.40 ± 0.06
Minimum	0.16 ± 0.04	0.19 ± 0.08	26.39 ± 5.20	0.03 ± 0.01	0.04 ± 0.02	0.11 ± 0.02	0.10 ± 0.02

Table 3
Summary of the hazard parameters in the two groups.

Group	H_{in}	H_{ex}	Dγ	AED (mSv/y) Public	AED (mSv/y) Workers	ELCR ($x10^{-3}$) Public	ELCR ($x10^{-3}$) Workers
Group 1	0.606	0.601	83.65	0.10	0.12	0.36	0.33
Group 2	0.39	0.325	50.85	0.06	0.07	0.22	0.20
Recommended* [18]	<1	<1		0.07		0.29	

world averages while the values of ^{238}U and ^{232} Th in Group 2 are near the values of the world averages. The lower value of ^{40}K than the world average could be due to no/less use of fertilizer around the quarry. The average values of H_{ex} and H_{in} of the two groups, as shown in Table 3, were below the recommended value, which is 1 mSv/y.

The radiological risk parameters of the two group of sampling sites are shown in Table 3. The result is compared and the H_{in} and H_{ex} of Group 1 are almost twice that of the first group and this shows the longitudinal and altitudinal variation affects the radiation. The difference could be due to altitudinal variation rather than longitudinal since quarrying is done closer to the road (at lower altitude) first than at higher altitude.

In all individual and groups of sample locations the obtained average values of AED for the public and workers in Group 1 were found to be elevated with respect to the recommended value of 0.07 mSv/y [2] to outdoor. The ELCR values in Group 1 were also found

Table 4
Results of this study compared with other countries studies on soil sample matrix in (Bq/kg).

Countries	^{238}U	^{232}Th	^{40}K	Reference
Ghana	–	29.40	120.92	[14]
Egypt	46.5	62.5	650	[28]
Iraq	–	8.6	393	[29]
India	19.72	220.5	920.2	[30]
Malaysia	–	83.39	138.98	[31]
Gabon	–	63	355	[32]
Malaysia	61.74	61.96	381.56	[17]
Nigeria	45.1	146.5	539.6	[21]
Ethiopia (Metekel)		70	330	[33]
Ethiopia (Haramaya)	23.72	111.5	794.26	[34]
Present Study	51.9	68.32	220.0	
World average	**33**	**45**	**420**	[26]

higher from the value of 0.29×10^{-3} [18] which is also recommended by UNSCEAR [26].

Safety provisions should be provided to workers in quarry sites to protect from Stochastic effect of radiation in the future. In addition, after the termination of quarry activities and before rehabilitating the areas for urbanization and other human activities, such quarry sites should be monitored by the pertinent regulatory bodies.

As shown in Table 4., the obtained results were compared with other countries' studies.

In this study, the result obtained for average activity concentration of ^{238}U was higher compared with published data of results of some countries listed in Table 4 except that of Malaysia [17], whereas the ^{232}Th value from this study were lower than others in published literature from Nigeria, India, Ethiopia, and Malaysia. On the other hand, all the obtained results for ^{40}K of this study were much lower when compared with others from different countries except Ghana as presented in Table 4. All the values obtained in this study at Hakim Gara, as shown in Table 4, are lower than the recommended control limit of 1 Bq/g for ^{238}U and ^{232}Th and 10 Bq/g for ^{40}K [27] to be classified as NORM requiring regulation for its control. However, the results for ^{238}U and ^{232}Th, were all significantly above the world-wide average values for normal soil as reported by UNSCEAR [26]. Values of the average external and internal hazard indices found were also below the permissible limit of unity. And hence the results obtained show low exposure to natural radioactivity and may not be of immediate radiological concern as long as safety measures and reduced staying time culture are in place. Hence, it is believed that this study provides the basis for further studies and proper regulatory and policy decisions before urbanization completely covers such similar study areas.

4. Conclusion

Radioactivity concentrations of ^{238}U, ^{232}Th and ^{40}K of two sites of Hakim Gara quarry site were determined. Analyses of the study were done to compare the results with worldwide average and the limits set by IAEA. Location-wise, group 1 that is considered as the first site revealed higher activity concentrations of ^{238}U, ^{232}Th and ^{40}K as compared to group 2. The averages of activity concentrations of ^{238}U, ^{232}Th were higher than the world average while those of the remaining two were lower. However, the hazard levels of all the radionuclides were found to be below the recommended values and pose no health threats. Despite the results, the study indicates the need for regular follow-up and evaluation of the sites for the safety of the quarry workers and the public. More research works in this regard may be necessary to mitigate and protect workers in the sites from probable radiological impacts arising from quarry activities.

Author contribution statement

Tadele Negash Regassa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Gelana Amente Raba: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Berhanu Mengistu Chekol: Analyzed and interpreted the data; Wrote the paper.

David Okoh Kpeglo: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

No data was used for the research described in the article.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Additional information

No additional information is available for this paper.

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.

Acknowledgment

The author would like to acknowledge Ethiopian Technology Authority (ETA), International Atomic Energy Agency (IAEA), College of Natural and Computational Sciences of Haramaya University (HU) and School of Nuclear and Allied Sciences (SNAS) - University of Ghana for supporting this doctoral fellowship research part. This experimental work was carried out in the Gamma laboratory facility in Radiation Protection Institute (RPI) of Ghana Atomic Energy Commission (GAEC), and the author is thankful to the ETA and RPI staff members for all their kind support from collection of samples at the site to activities in the laboratory process till this result is achieved. Finally, the author would like to dedicate this article to Prof. E.O. Darko who was the main advisor for the research part of this program at SNAS-University of Ghana and passed away during the final drafting process of this article.

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