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RADIOLOGICAL HAZARD LEVELS OF CONSTRUCTION ROCKS EXCAVATED FROM QUARRIES IN KERICHO COUNTY, KENYA

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ABSTRACT

The study determined the natural activity concentration levels of ^{40}K, ^{232}Th and ^{238}U in rocks used for construction from the 15 selected quarries in Kericho County, Kenya through Gamma-ray Spectrometric analysis at the Physical Sciences department of South Eastern Kenya University (SEKU). IAEA procedures were followed from sample collection, preparation, and measurement. Samples were collected, crushed, oven dried at 105℃, weighed and packed in sealed containers and kept for four weeks for secular equilibrium to be achieved between ^{226}Ra and ^{232}Th. The average activity concentration of ^{232}Th, ^{238}U and ^{40}K were 101 ± 5 Bq/kg, 56 ± 3 Bq/kg and 1100 ± 55 Bq/kg and ranged from 41 ± 2 to 138 ± 7 Bq/kg, 26 ± 1 to 116 ± 6 Bq/kg and 512 ± 26 to 1919 Bq/kg ± 96 Bq/kg respectively. The average external and internal hazard indices were 0.8 mSv/y and 0.9 mSv/y respectively. Radium equivalent ranged from 222 ± 11 Bq/kg to 366 ± 18 Bq/kg with an average value of 285 ± 14 Bq/kg which was below the permissible limit of 370 Bq/kg; therefore, the excavated rocks for construction from the selected quarries in Kericho county poses insignificant health risk to the general population and quarry workers.

I. INTRODUCTION

Mineral mining or the extraction of rocks exposes workers to ionizing radiation from the primordial radioisotopes found in the rocks [1]. The radioactive isotopes ^{238}U and ^{232}Th, as well as their decay products, as well as the radioactive isotope ^{40}K which are found in the earth's crust that is soil, rocks and water expose people to ionizing radiation at doses that are either outdoor or indoor [2]. Indoor exposure results from radiations emitted from the building materials such as soil, rocks and even the ground where the building is constructed. Radiations from the primordial radionuclides present in these construction rocks may pose a risk to miners, masons, transporters, the populace around the quarries and inhabitants of the houses built from these rocks if the radiation is beyond the permissible levels [3]. The annual effective dose rate (AEDR) in both the outdoor and indoor settings should not exceed 1mSvy^{-1}and the average radium equivalent (Ra_{eq}) should be less than the permitted maximum of 370 BqKg^{-1} in both the outdoor and indoor environments [4]. Natural radioactivity exposure arising from radiations depends on the geological conditions, and therefore the levels in rocks are different. Quite a few the building materials (soil and rocks) have natural primordial radioisotopes of ^{238}U and ^{232}Th series [5]. The decay series/chain of ^{238}U and ^{232}Th. Potassium-40 adds to the external and internal radiation exposure for residents of rock-built homes where gamma radiation is emitted from walls, ceilings, and floors when radon, thorium and progeny are ingested [6]. Ionizing radiations are emitted when an unstable nucleus decays to be stable [7]. The earth's crust is made of sedimentary rocks, metamorphic rocks, and igneous rocks [8]. Documentations from radiometric surveys show that igneous rocks have elevated levels of ^{40}K, ^{238}U and ^{232}Th [9]. Apart from inhaling radionuclides (radon gases and dust particles), these radionuclides get into our body systems through food uptake found in plants, notably ^{40}K. Human consumption of food grown in regions with potentially elevated levels of background radionuclides is at significant risk [10]. Radium, uranium, and thorium in their natural states and their decay products as well and potassium are examples of NORM materials that have not been altered by human action [11]. The combination of radiation from highly energetic particles, such as the sun and stars that enter the earth's atmosphere (cosmic radiations) and radionuclides, such as ^{238}U and ^{232}Th, their decay products, and the naturally occurring ^{40}K found on the earth's surface forms background radiation that exposes human beings either internally or externally to radioactive substances [12]. Because ^{40}K and ^{14}C are present in food, soil and water, they form internal radiations in human bodies [13]. The current research examined the hazard levels of ^{238}U, ^{232}Th, and ^{40}K on the construction rocks excavated within Kericho county.

II.1 STUDY AREA

The study took place in Kericho County's quarries. It is situated in the Great Rift Valley's southern rift region, $35^0$02` and $35^0$40` east longitude and the equator and latitude $0^0$23` south, with a height of roughly 2002m above sea level, it covers an area of 2111 square kilometres. The county has an estimated population of 901,777 per the 2019 Kenya population and housing census [14]. Samples were collected from the following quarries: Tunnel and Kimondui in Kipkelion West, Kedowa, Jagoror, Kipsirichet and United in Kipkelion East, Rockland, Kisumu Concrete and Rai cement in Soin-Sigowet, Kibingei in Kericho West, Laliat and Chepsetion in Kericho East, Agisiek, Kibugat and Maburo in Bureti sub-county. Figure 1 shows the map of the study area.

Figure 1: Map of Kericho County.
Source: [15].

The selected areas were chosen because most residents and others from neighboring counties source rocks used for construction from Kericho County. Therefore, there is a need for research to determine the safety of materials used for the building of either domestic or commercial houses.

II.2 SAMPLE PREPARATION

Two rocks' samples, each weighing 200g, were collected from each quarry using a 1000ml plastic container, packed and labelled using unique codes. The 30 collected samples were crushed, sieved in 1mm wire mesh, and dried up in an oven at a temperature of 105^0C for 24hrs to enable direct calculations of specific activity concentrations of radioisotopes. The samples were weighed and packed in 200ml plastic containers, tightly closed, and wrapped with aluminum foil to prevent the leakage of uranium, radon, and thorium. The samples were kept for four weeks to achieve secular equilibrium between ^{226}Ra and ^{232}Th [16].

II.3 GAMMA RAY CALIBRATION

Each sample was placed in a detector and monitored for a period 8 hours making it possible to run two samples per day. After background correction on the obtained spectra, for ^{40}K, the gamma peak with a centroid at 1460keV was used, ^{214}Bi (609 keV), 1765 keV for ^{238}U, ^{208}Ac and ^{208}Ti (583keV), 2615 keV for ^{232}Th while ^{214}Pb at 352keV and ^{212}Pb at 239keV photopeak's were used for activities of ^{238}U and ^{232}Th respectively.

II.4 SAMPLE ANALYSIS

II.4.1 Natural Activity Concentrations

The ready to measure rock samples were placed in the lead shielded NaITI gamma detector for an average of 8 hours to accumulate gamma counts and achieve well-formed photo-peaks. The activity of the NORMs was determined using the method of comparison given by equation 1 [17].

$$\frac{M_r A_r}{I_r} = \frac{M_s A_s}{I_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where; M, A, I, r and s represent mass, activity, intensity, reference and sample respectively.

II.4.2 Radium Equivalent (Ra_{eq})

The phrase radium equivalent refers to the proportionate total of ^{226}Ra, ^{232}Th, and ^{40}K activities based on the premise that 1BqKg^{-1} of ^{226}Ra, 0.7BqKg^{-1} of ^{232}Th, and 13BqKg^{-1} of 40K generate the same gamma dose rate as 1Bqkg^{-1} of ^{226}Ra [18].

Calculating the radium equivalent was based on the empirical relationship shown in Equation 2.

$$Ra_{eq} = AC_{Ra} + 1.423AC_{Th} + 0.077AC_{K} \ldots\ldots(2)$$

AC_{Ra}, AC_{Th}, and AC_{K} are the average activity concentrations in $Bqkg^{-1}$ of ^{226}Ra, ^{232}Th, and ^{40}K in $BqKg^{-1}$, respectively.

II.4.3 External Hazard Index (H_{ex})

Radiation from naturally occurring radionuclides found in construction rocks may cause external exposure to gamma radiation, measured using an external hazard index. If the external danger index of the radiation is less than one, the consequences are insignificant [19]. H_{ex} was determined by employing equation 3.

$$H_{ex} = \frac{AC_{Ra}}{370} + \frac{AC_{Th}}{259} + \frac{AC_{K}}{4810} \ldots\ldots\ldots\ldots(3)$$

AC_{Th}, AC_{Ra}, and AC_{K} represent the average activity concentrations of ^{232}Th, ^{226}Ra, and ^{40}K.

II.4.4 Internal Hazard Index (H_{in})

Inhalation of terrestrial radionuclides due to presences of ^{40}K, ^{232}Th, and ^{238}U (^{226}Ra) in construction rocks causes internal harm [19]. H_{in} was calculated using equation 4 [18].

$$H_{in} = \frac{AC_{Ra}}{185} + \frac{AC_{Th}}{259} + \frac{AC_{K}}{4810} \ldots\ldots\ldots\ldots(4)$$

AC_{Ra}, AC_{Th}, and AC_{K} are the mean activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in $BqKg^{-1}$ respectively. If the value is less than a unit, then the effects of the radiation are negligible to human organs [5].

III. RESULTS AND DISCUSSIONS

III.1. NATURAL ACTIVITY CONCENTRATIONS

Due to unequal distribution of primordial radionuclides and geological location, activity concentrations varied from one quarry to another. The average activity concentration of ^{232}Th, ^{283}U, and ^{40}K were 102 ± 5 Bq/kg, 56 ± 3 Bq/kg and 1845 ± 92 Bq/kg and ranged from 41 ± 2.09 to 138 ± 7 Bq/kg, 27 ± 1 to 116 ± 6 Bq/kg and 1042 ± 52 to 2690 ± 135 Bq/kg respectively. ^{238}U, ^{232}Th and ^{40}K average activity concentrations were above the world's average value of 50Bq/kg, 50Bq/kg and 500Bq/kg respectively. All the quarries showed a higher value for activity concentration of potassium-40 compared to world's average value. Seven quarries had a value of activity concentrations of ^{238}U being below the world average value. The average activity concentration of ^{40}K was higher compared to that of ^{232}Th and ^{238}U and is attributed to the minerals such as phosphate, quartzite, sandstone, and granite rich radioactive materials. Table 3.1 shows the activity concentration of the radionuclides from the collected samples.

Table 1: Activity Concentration of the Collected Samples.

Average Activity Concentration of the Radionuclides (Bq/kg)			
	^{232}Th	**^{226}Ra**	**^{40}K**
MIN	41±2	26±1	512±26
MAX	138±7	116±6	1919±96
AVERAGE	101±5	56±3	1100±55

Source: Authors, (2022).

Though the reported findings on activity concentrations being higher than the world's recommended values, they are far much below the exemption limits of 1000Bq/kg, 1000 Bq/kg and 100000 Bq/kg for ^{232}Th, ^{238}U and ^{40}K respectively, thus making the rocks excavated in Kericho county quarries safe for use.

III.2. RADIUM EQUIVALENT

The radium equivalent was determined using equation 2 and the results were graphically illustrated in Figure 2. The mean radium equivalent for the samples was 344 ± 17 Bq/kg which does not exceed the proposed radioactivity criterion levels hence below the recommended maximum value of 370 $Bqkg^{-1}$ [9]. Radium equivalent for all the individual samples was graphically represented in Figure 2.

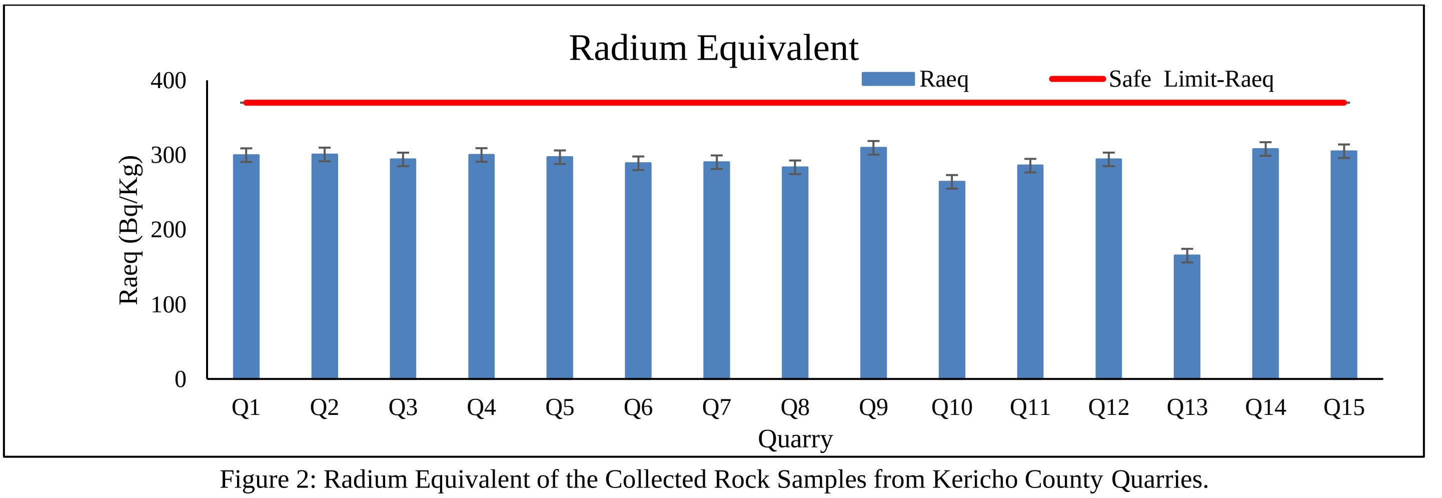

Figure 2: Radium Equivalent of the Collected Rock Samples from Kericho County Quarries.
Source: Authors, (2022).

All the collected samples recorded a radium equivalent which was less than the world's recommended maximum value of 370 Bq/kg as shown in Figure 2. The radium equivalent values shown in Figure 3.1 ranged between 165 ± 8 Bq/kg and 309 ± 15 Bq/kg. Therefore, the construction rocks pose minimal radiological risk since all the radium equivalent values at the study area were less than the world's permissible maximum value of 370 Bq/kg [20].

III.3. HAZARD INDICES

External exposure due to gamma radiations was determined using equation 3. The values obtained averaged at 0.8 mSv/y, which was less than the worlds recommended value of 1 mSv/y [21]. Determination of internal exposure due to inhalation and ingestion of primordial radionuclides was done by employing equation 4. H_{in} averaged at 0.9 mSv/y, which was less than the worlds recommended value of 1 mSv/y. Figure 3 shows the hazard indices values obtained from the analysis of the collected samples.

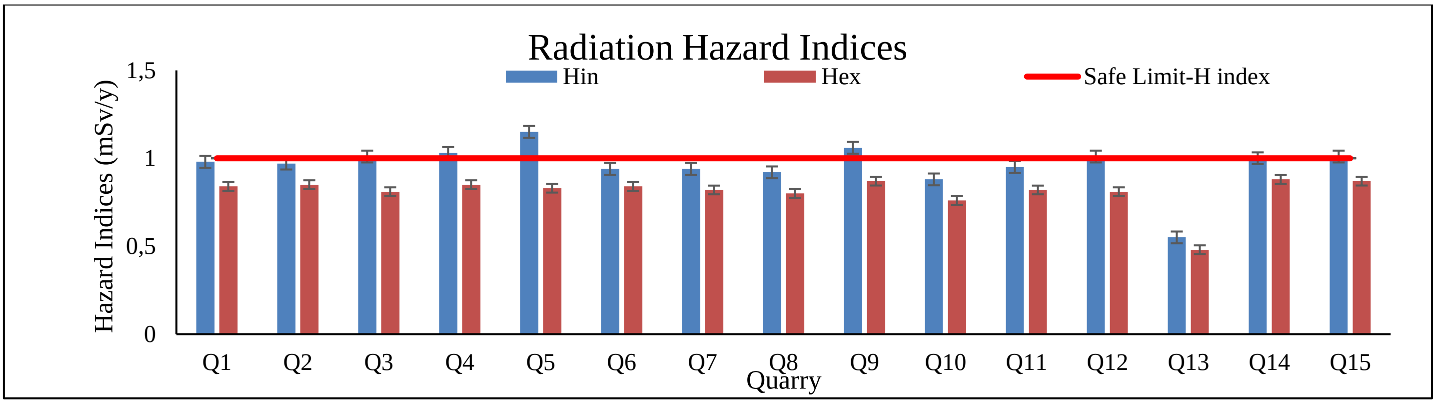

Figure 3: Hazard Indices of the Collected Rock Samples from Kericho County Quarries.
Source: Authors, (2022).

From Figure 3, the minimum and maximum external hazard index were 0.4 ± 0.02 and 0.8 respectively. H_{in} obtained ranged from 0.5 mSv/y to 1.1 mSv/y. Most samples posted hazard indices below a unit while the rest of the samples were within the recommended criterion limit of 100 mSv/y. This was because of varying activity concentration of ^{238}U, ^{232}Th and ^{40}K. This made some samples hazard indices to be higher than a unit but still below the recommended exceptional value of 100 mSv/y hence posing minimal significant potential health threat to the general population.

IV. CONCLUSIONS

Determination of the natural radioactivity levels in rocks used for construction in Kericho County from selected quarries has been done using NaI(TI) gamma ray spectrometer. The average activity concentration of ^{232}Th, ^{238}U, and ^{40}K were 101 ± 5 Bq/kg, 56 ± 3 Bq/kg and 1100 ± 55 Bq/kg respectively. The radium equivalent ranged from 165 ± 8 Bq/kg to 309 ± 15 Bq/kg with an average value of 285 ± 14 Bq/kg which is below the permissible limit of 370Bq/kg. The average external hazard index was 0.8 mSv/y while the average internal hazard index was 0.9 mSv/y. They were less than acceptable limit of 1mSv/y. Though the activity concentrations were above the worlds recommended values, they were below the exemption limits, thus, rocks excavated from Kericho county are safe for use. Since this research work did not take into consideration Radon concentration in the underground water sources around the quarries where rocks are excavated, there is need for determination of Radon – 222 concentration levels in underground water sources around the studied quarries.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Chepngetich Betty, Fred Wekesa Masinde, Enoch Kipnoo Rotich and Conrad Khisa Wanyama.
Methodology: Chepngetich Betty, Fred Wekesa Masinde, Enoch Kipnoo Rotich and Conrad Khisa Wanyama.
Investigation: Chepngetich Betty, Fred Wekesa Masinde, Enoch Kipnoo Rotich and Conrad Khisa Wanyama.
Discussion of results: Chepngetich Betty, Fred Wekesa Masinde, Enoch Kipnoo Rotich and Conrad Khisa Wanyama.
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Writing – Review and Editing: Chepngetich Betty, Fred Wekesa Masinde, Enoch Kipnoo Rotich and Conrad Khisa Wanyama.
Resources: Chepngetich Betty, Fred Wekesa Masinde, Enoch Kipnoo Rotich and Conrad Khisa Wanyama.
Supervision: Chepngetich Betty, Fred Wekesa Masinde, Enoch Kipnoo Rotich and Conrad Khisa Wanyama.
Approval of the final text: Chepngetich Betty, Fred Wekesa Masinde, Enoch Kipnoo Rotich and Conrad Khisa Wanyama.

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VII. CONFLICT OF INTEREST

The author declares no conflict of interest regarding publication of this paper.

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