HiLL PUBLISHING

OAJRC Material Science, 2024, 6(2), 39-47
https://www.hillpublisher.com/journals/oajrcms/
ISSN Online: 2632-2072

Natural Radioactivity Levels and Associated Radiological Hazard in Cement Raw Material Samples Extracted from Eastern and Southwestern Uganda

Winston Tumps Ireeta[1,*], Dennis Muyimbwa[1], Benjamin Jingo[1,2]

[1]Department of Physics, School of Physical Sciences, College of Natural Sciences, Makerere University, Kampala 7062, Uganda.
[2]Department of Physics, Faculty of Science, Gulu University, Gulu 166, Uganda.

How to cite this paper: Winston Tumps Ireeta, Dennis Muyimbwa, Benjamin Jingo. (2024) Natural Radioactivity Levels and Associated Radiological Hazard in Cement Raw Material Samples Extracted from Eastern and Southwestern Uganda. *OAJRC Material Science*, 6(2), 39-47.
DOI: 10.26855/oajrcms.2024.12.001

Received: August 27, 2024
Accepted: September 25, 2024
Published: October 22, 2024

***Corresponding author:** Winston Tumps Ireeta, Department of Physics, School of Physical Sciences, College of Natural Sciences, Makerere University, Kampala 7062, Uganda.

Abstract

This study was to determine the natural radioactivity levels of ^{226}Ra, ^{232}Th, and ^{40}K in cement raw material (limestone, sand, kaolin clay, magnesium oxide, and pozzolana) samples extracted from Eastern and Southwestern Uganda. The specific activity concentration of each of these radionuclides in each sample was determined using a Sodium Iodide scintillation detector to assess the radiological hazard associated with them. The average specific activity concentration values of ^{226}Ra, ^{232}Th, and ^{40}K in the samples from Southwestern Uganda were 94.9 Bqkg^{-1}, 97.1 Bqkg^{-1}, and 484.8 Bqkg^{-1} respectively while in samples from Eastern were respectively 30.2 Bqkg^{-1}, 58.7 Bqkg^{-1} and 557.5 Bqkg^{-1}. The average outdoor absorbed gamma dose rate value for samples from Southwestern Uganda was two times higher than the world average value of 59 nGyh^{-1}. The average radium equivalent activity values, the average external and internal hazard index values, and the average outdoor annual effective dose values obtained for samples from either region were within the safe recommended limits. Hence, the samples posed no significant radiological hazard to both miners and the public.

Keywords

Natural radioactivity levels; Cement raw materials; Radiological safety analysis; Gamma-ray spectrometry

1. Introduction

Like other building raw materials extracted from the earth's crust, cement raw materials such as pozzolana, limestone, and Kaolin-clay contain varying amounts of terrestrial radionuclides [1]. Terrestrial radionuclides are naturally occurring radioactive nuclides from the earth's crust. They are present in every environmental media (air, water, soil, and biota). For this reason, human beings are always exposed to ionizing radiations such as gamma rays from terrestrial radionuclides [2].

Cement raw materials mainly consist of soil and rock components. Radiation from such sources primarily originates from naturally occurring radioactive materials (NORMs); the radionuclide ^{40}K, and the radionuclides in the decay series of ^{238}U and ^{232}Th. The decay chain segment beginning with ^{226}Ra in the ^{238}U series is radiologically the most significant, leading to frequent reference to ^{226}Ra instead of ^{238}U [3]. The concentration levels of ^{238}U, ^{232}Th, and ^{40}K vary in soil and rock structures, depending on the area's local geology and geographic conditions [4]. The global average specific activities of ^{226}Ra, ^{232}Th, and ^{40}K in the earth's crust are estimated at 32 Bqkg^{-1}, 45 Bqkg^{-1}, and 412 Bqkg^{-1}, respectively [5].

Eastern and Southwestern Uganda areas are graced with many mineral deposits including cement raw materials such as

limestone, kaolin-clay, and pozzolana [6]. Limestone primarily consists of calcium and magnesium carbonates. It is classified into various types based on source, composition, structure, and geological formation [7]. Pozzolana is a silica-rich or silica-and-alumina-rich rock. In the presence of water, pozzolana reacts intensely with limestone to produce a strong, chemical-resistant cement hence reducing the need for costly limestone. Kaolin-clay is a product of the chemical weathering of feldspar-rich rocks, including pegmatites, certain siltstones, and schists. Sand is commonly found near clay deposits in wetlands and on lake shores [8]. Since they are extracted from the earth's crust, cement raw materials may contain fragments from igneous and metamorphic rocks. According to studies by Ademola & Ayeni [9], Adewale et al. [10], and Şahin Bal [11] it has been established that soils and rocks of granite composition contain substantial concentrations of terrestrial radionuclides. As a result, igneous rocks like granite are linked to elevated levels of radiation [2]. Engaging activities such as raw material mining for cement production represents a significant source of exposure to radiation from NORMs [2]. Prolonged exposure to ionizing radiation can result in radiation-induced health effects such as cancers [12]. Among miners, lung cancer is the most common observed effect and it is attributed to inhalation of radiation [13].

Kisolo et al. [14], Mugaiga et al. [15], and Silver et al. [16] found high specific activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in rocks and soils of Eastern and Southwestern Uganda in contrast to values reported in the UNSCEAR [2] publication. However, there is little to no information available regarding the natural radioactivity concentration levels of these terrestrial radionuclides in cement raw materials mined from these regions of the country. Therefore, this study aims to determine the radioactivity levels of ^{226}Ra, ^{232}Th, and ^{40}K in limestone, sand, kaolin clay, magnesium oxide, and pozzolana samples to assess their associated radiological hazards to miners and workers at crush sites. The results of this study will provide valuable insights to the Atomic Energy Council (AEC) and policymakers to establish guidelines and protection measures for the utilization of the studied cement raw materials in the country. Additionally, the research will hold significant importance for the cement manufacturing industries in Eastern and Southwestern Uganda, enabling them to check on their raw materials where necessary.

2. Materials and Methods

2.1 Sample Collection

All samples were collected from mine contractors who supply cement companies in Eastern and Southwestern Uganda with raw materials. The map showing the location of the mines where the studied samples are extracted is indicated in Figure 1. A total of 15 samples weighing from 0.5 to 2 Kg were considered for the study. Of these, eleven (11) samples were collected from Southwestern and four (4) from Eastern Uganda. No specific criteria were applied during sample collection due to restricted access to the mines. The samples were carefully packed into polythene bags to prevent any cross-contamination and then labelled according to guidelines by IAEA [17]. Details about the collected samples are indicated in Table 1.

Table 1. Details about the studied cement raw materials samples

Sample Name	Type	Source	Sample code
Limestone	Dura	Dura (Kamwenge)	HD
	Moderate	Muhokya (Kasese)	HM
	South Extreme	Hima (Kasese)	HSE
	Carbonatite	Tororo	TL 1
	Carbonatite	Katikekile (Moroto)	TL 2
Magnesium oxide	Magnesium oxide	Hima (Kasese)	HHM
Sand	Sand	Katunguru (Rubirizi)	HSS
	Sand	Katunguru (Rubirizi)	HS
Clay	Pink Kaolin	Mutaka (Bushenyi)	HK 1
	White Koalin	Buhweju	HK 2
	White Kaolin	Mutaka (Bushenyi)	HC
	White Kaolin	Moni (Mbale)	TC
Pozzolana	Pozzolana	Harugongo (Kabalore)	HP
	Lava Ash	Bunyaruguru (Rubirizi)	HLA
	Pozzolana	Chemangala (Kapchorwa)	TP

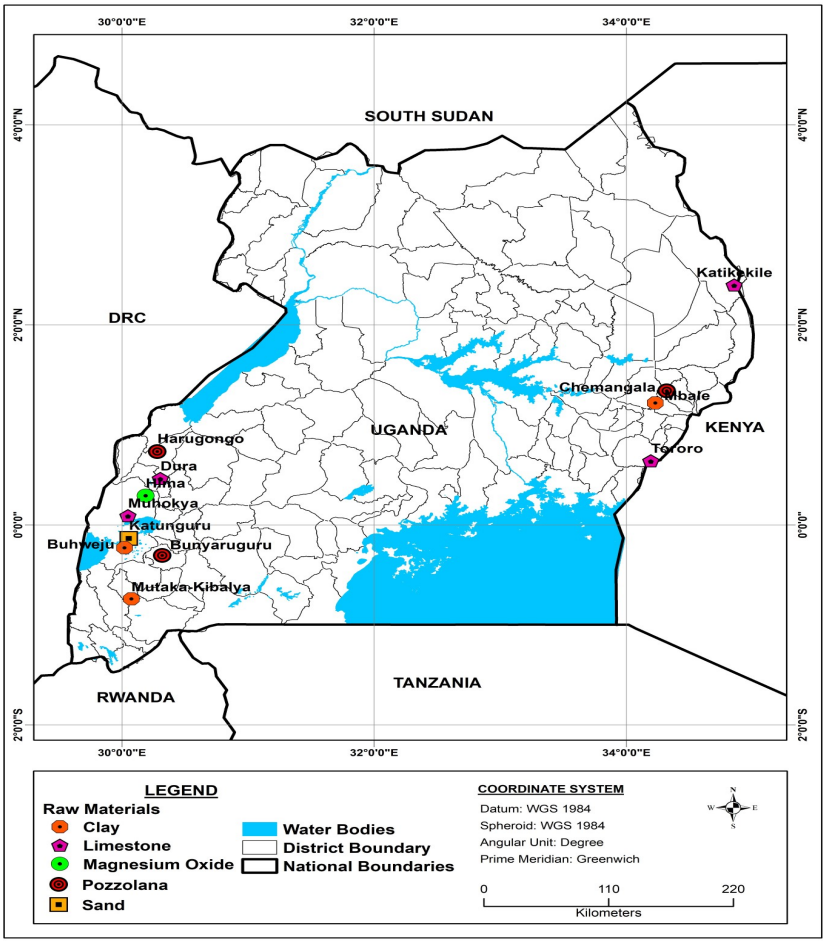

Figure 1. A Map of Uganda showing the studied limestone, clay, sand, magnesium oxide, and pozzolana mines locations (Arc GIS).

2.2 Sample Preparation

At the laboratory, cement raw material samples were laid out on plastic trays with raised edges and left to dry at room temperature for 48 hours before being ground into a fine powder. The ground samples were standardized by passing them through a 2mm fine mesh sieve and then subjected to complete moisture removal by oven-drying at a temperature of 105 °C for 24 hours, in accordance with the recommendations of IAEA [17]. After moisture removal, samples were cooled in a moisture-free environment. Each prepared dry sample was carefully weighed using an electronic balance and then placed into a plastic Marinelli beaker. The beakers were then tightly sealed to prevent any release of radon gas. The sealed samples were stored for more than 30 days before gamma-ray counting to allow ^{226}Ra and ^{232}Th to attain secular equilibrium with their short-lived daughters, ^{222}Rn and ^{220}Rn, respectively [18]. After reaching a state of secular equilibrium, each sample was subjected to a gamma ray spectrometric analysis using a 2" × 2" NaI (TI) scintillation gamma detector (Model 905–3) provided by ORTEC.

2.3 Gamma Energy Spectral Analysis and Characterization

Prior to measurements, the detector was calibrated for energy and efficiency. Energy calibration was done using the standard caesium-137 sample, while efficiency calibration was done using caesium-137 and cobalt-60 standard samples. Following the calibration process, each Marinelli beaker containing a sample was positioned on the detector for counting. The system was left to operate for a duration of 6000 seconds to allow a clear gamma-ray spectrum of the radionuclides contained in the sample to build upon the computer screen. Each net sample spectrum after background subtraction was then stored in the computer using the ORTEC MAESTRO V7 software commands and later analyzed. The spectra were analyzed for detectable gamma energies, specifically 295.2 keV and 351.9 keV of ^{214}Pb for ^{226}Ra, 510.7 keV of ^{208}TI, and 911.2 keV of ^{228}Ac for ^{232}Th, and 1460.8 keV

for ^{40}K. To determine the radioactivity levels of ^{226}Ra, ^{232}Th, and ^{40}K in the samples, their respective specific activity (A) concentrations were calculated.

2.4 Specific Activity Concentration in the Samples

The specific activity concentration (A) in Bqkg^{-1} of ^{226}Ra, ^{232}Th, and ^{40}K in each sample was calculated using Equation (1) [15].

$$A = \frac{N_p}{tm_j b_\gamma e_\gamma} \quad (1)$$

where m is the dry weight of the sample j in kg, N_p is the net peak area of the gamma peak of interest, t is the counting time, b is the emission probability of a particular gamma energy and e is the detector efficiency at a gamma energy γ emitted by the standard.

2.5 Assessing the Radiological Safety of the Samples

The radiological safety of the samples was assessed by analyzing the determined radium equivalent activity, the external and internal hazard indices, the outdoor gamma dose rate, and annual effective dose values.

2.5.1 Radium equivalent activity

The radium equivalent activity (Ra_{eq}) index ensures the uniform distribution of ^{226}Ra, ^{232}Th, and ^{40}K in a sample, effectively representing the activity concentration of these radionuclides while accounting for their associated radiation hazard. Radium equivalent activity was calculated using Equation (2) [19].

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (2)$$

where A_{Ra}, A_{Th}, and A_K are specific activities in Bqkg^{-1} of ^{226}Ra, ^{232}Th, and ^{40}K respectively. Equation (2) assumes that 370 of ^{226}Ra, 259 of ^{232}Th, and 4810 of ^{40}K in Bqkg^{-1} all produce the same gamma-ray dose rate [20]. For a building material or its end products to be considered radiologically safe for use, its maximum Ra_{eq} value should be less than 370 Bqkg^{-1} [20, 21]. This ensures that the external gamma dose remains below 1.5 mSvy^{-1} [2, 22].

2.5.2 External and internal exposure hazard indices

The external radiation hazard index (H_{ex}), corresponding to ^{226}Ra, ^{232}Th and ^{40}K was calculated using Equation (3) [19].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (3)$$

To mitigate the radiation hazard to respiratory organs such as lungs from radon-222, Krieger [23] proposed halving the acceptable maximum concentration of radium. This criterion known as the internal hazard index (H_{in}) was determined using Equation (4) [19].

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

Each index value should be less than 1 for the radiation hazard to be negligible [3].

2.5.3 Outdoor absorbed gamma dose rate and annual effective dose

Assuming negligible contributions from other terrestrial radionuclides like ^{235}U, the outdoor absorbed dose rate (D) in the air at one meter above the ground was calculated using Equation (5) [2].

$$D = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (5)$$

where 0.462 nGyh^{-1}per Bqkg^{-1}, 0.604 nGyh^{-1}per Bqkg^{-1}, and 0.0417 nGyh^{-1}per Bqkg^{-1} are activity concentration to outdoor dose rate conversion coefficients corresponding to ^{226}Ra, ^{232}Th and ^{40}K respectively [2]. The population-weighted average outdoor dose rate value due to gamma radiation from natural sources is 59 nGyh^{-1} [2, 5].

To assess the health effects of annual absorbed dose rates, the outdoor annual effective dose was estimated using the conversion coefficient from absorbed dose in the air to effective dose (0.7 SvGy^{-1}) and the outdoor occupancy factor (0.2) [2, 5]. The outdoor annual effective dose (E) in mSvy^{-1} was calculated from Equation (6) [2].

$$E = D \times 10^{-6} \times 8760 \times 0.2 \times 0.7 \quad (6)$$

where D is the outdoor absorbed dose rate and 8760 is the total occupancy time in hours for the whole year (assuming 365 days). The annual effective dose (E) from natural sources of public exposure should not exceed 1 mSv a year [24, 25].

3. Results and Discussions

The calculated specific activity concentration values of ^{226}Ra, ^{232}Th, and ^{40}K are indicated in Table 2 and Table 3 for samples from Eastern and Southwestern Uganda respectively. From Table 2, values ranged from 2.3 ± 0.2 to 68.4 ± 2.7 Bqkg^{-1} with an average of 30.2 ± 1.5 Bqkg^{-1} for ^{226}Ra, 26.3 ± 0.9 to 117.8 ± 3.0 Bqkg^{-1} with an average of 58.7 ± 1.7 Bqkg^{-1} for ^{232}Th and 326.5 ± 5.2 to 1037.1 ± 15.5 Bqkg^{-1} with an average of 557.5 ± 9.1 Bqkg^{-1} for ^{40}K. The highest specific activity concentration of the three radionuclides was registered from the pozzolana (TP) sample whereas the lowest concentration was obtained from the Clay (TC) sample. The high specific activity concentration of these radionuclides in the pozzolana sample could be due to their high granite composition of the pozzolana since the studied pozzolana are volcanic materials.

Table 2. Specific activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in cement raw material samples from Eastern Uganda

Sample Name	Sample code	Specific Activity (Bqkg^{-1})		
		^{226}Ra	^{232}Th	^{40}K
Limestone	TL 1	39.0 ± 1.2	41.7 ± 1.0	327.8 ± 5.0
	TL 2	2.3 ± 0.2	48.9 ± 1.1	538.6 ± 6.5
Clay	TC	11.2 ± 0.7	26.3 ± 0.9	326.5 ± 5.2
Pozzolana	TP	68.4 ± 2.7	117.8 ± 3.0	1037.1 ± 15.5
Average		**30.2 ± 1.5**	**58.7 ± 1.7**	**557.5 ± 9.1**

Table 3. Specific activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in cement raw material samples from Southwestern Uganda

Sample Name	Sample Code	Specific Activity (Bqkg^{-1})		
		^{226}Ra	^{232}Th	^{40}K
Limestone	HD	297.8 ± 3.5	202.7 ± 2.3	388.9 ± 5.9
	HM	76.4 ± 2.2	61.3 ± 1.7	432.7 ± 7.6
	HSE	71.4 ± 2.0	76.2 ± 1.6	472.3 ± 7.4
Magnesium oxide	HHM	21.5 ± 0.9	86.7 ± 1.6	326.5 ± 5.4
Sand	HSS	5.1 ± 0.5	38.9 ± 1.1	306.0 ± 5.1
	HS	23.4 ± 0.9	43.8 ± 1.1	292.8 ± 4.8
Clay	HK 1	84.2 ± 2.0	62.6 ± 1.5	591.6 ± 7.7
	HK 2	72.0 ± 2.0	84.0 ± 1.8	779.5 ± 9.7
	HC	121.7 ± 3.0	94.0 ± 2.2	955.8 ± 12.4
Pozzolana	HP	151.4 ± 2.5	170.9 ± 2.2	356.5 ± 5.6
	HLA	119.2 ± 2.3	146.7 ± 2.0	430.4 ± 6.3
Average		**94.9 ± 2.2**	**97.1 ± 1.8**	**484.8 ± 7.4**

For samples from Southwestern Uganda (see Table 3) the specific activity values ranged from 5.1 ± 0.5 to 297.8 ± 3.5 Bqkg^{-1} with an average of 94.9 ± 2.2 Bqkg^{-1} for ^{226}Ra, 38.9 ± 1.1 to 202.7 ± 2.3 Bqkg^{-1} with an average of 97.1 ± 1.8 Bqkg^{-1} for ^{232}Th and 292.8 ± 4.8 to 779.5 ± 9.7 Bqkg^{-1} with an average of 484.8 ± 7.4 Bqkg^{-1} for ^{40}K. For ^{226}Ra and ^{232}Th, the highest specific activity concentrations were obtained from the Dura limestone (HD) sample and the lowest from the sand (HSS) sample. The high concentration of ^{226}Ra and ^{232}Th in the Dura limestone sample could be due to the above-normal quantities of dissolved Uranium in Dura [6]. The samples of clay (HC) and sand (HS) had the highest and lowest concentrations of the ^{40}K radionuclide respectively.

From Table 3, the average specific activity concentration values of ^{226}Ra, ^{232}Th and ^{40}K for all clay samples were greater than the world average values of 50 Bqkg^{-1}, 50 Bqkg^{-1}, and 500 Bqkg^{-1}, respectively for building materials extracted from the earth's

crust [22]. Clay is composed of pegmatites, quartz, and feldspar [6]. According to Hurley [26], these clay compositions contain radioactive elements. Therefore, the high specific activity concentration of these radionuclides in the clay samples could be due to the high concentration of pegmatites and feldspar.

The results in Table 2 and Table 3 reveal that the specific activity concentration of the ^{226}Ra, ^{232}Th, and ^{40}K radionuclides varied for all the studied limestone, clay, magnesium oxide, sand, and pozzolana samples. For each sample, ^{40}K had the largest specific activity concentration value whereas for ^{232}Th and ^{226}Ra their values varied. This could be due to the natural abundance of ^{40}K. Potassium-40 is found in most terrestrial materials at 0.012% abundance, while ^{232}Th is about 1.4 times more abundant than ^{238}U [5].

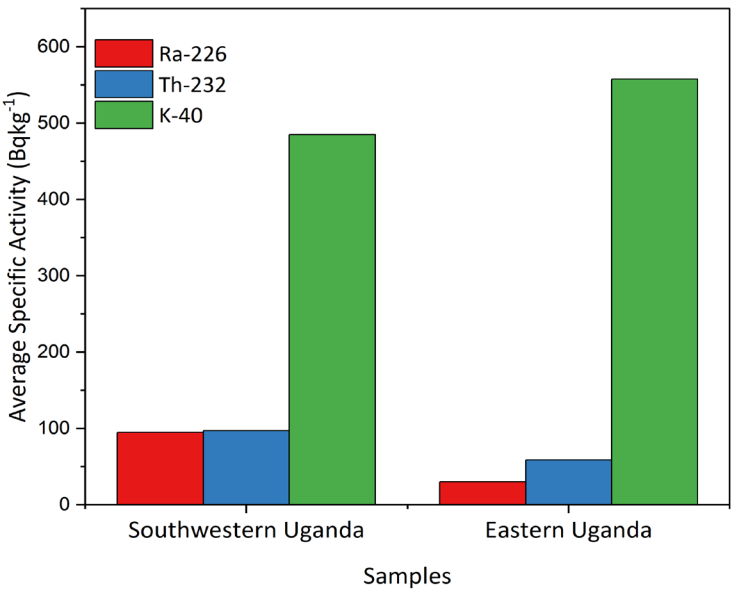

Figure 2. Average Specific Activity for samples from both regions.

On average, the specific activity values of ^{226}Ra and ^{232}Th for raw material samples from Southwestern Uganda (see Figure 2) where higher than those obtained for samples from Eastern Uganda. This could have been due to the presence of many pegmatites, and granites, in the soils and rocks of Southwestern Uganda [27]. Also, related studies done in Southwestern Uganda reported a high concentration of these radionuclides in soils and rocks [14, 16].

To assess the radiological safety of the samples, radiological indices presented in Table 4 and Table 5 were estimated. For samples from Eastern Uganda (see Table 4), the Ra_{eq} value for each sample including their average (157.1 ± 4.7 Bqkg^{-1}) was less than the maximum permissible value of 370 Bqkg^{-1} [19] for building materials. The Pozzolana sample had the largest Ra_{eq} value with the lowest obtained for the clay sample. The estimated values of the H_{ex} and H_{in} for each sample including their averages were lower than the permissible value of unity. The average D value (72.3 ± 2.1 nGyh^{-1}) for all samples was higher than the world average value of 59 nGyh^{-1} [2]. The E value for each sample including their average (0.09 ± 0.003 mSvy^{-1}) was less than the permissible limit of 1 mSv per year for public radiation exposure [24, 25]. Hence the studied limestone, clay, and pozzolana samples from Eastern Uganda are safe for miners and workers at crush sites.

For samples from Southwestern Uganda (see Table 5), the Ra_{eq} values for the Dura limestone (HD) and pozzolana (HP) samples were greater than the recommended value of 370 Bqkg^{-1}. According to the study, if these samples are to be used as raw materials or additives in cement production, their specific activity concentration should be monitored. The Ra_{eq} values for other samples including the total average value (271.0 ± 5.2 Bqkg^{-1}) were each less than the acceptable value of 370 Bqkg^{-1} [19]. The H_{ex} and H_{in} values for each sample except for the Dura limestone (HD) and pozzolana samples were less than the permissible value of unity. The average D value (122.7 ± 2.3 nGyh^{-1}) for all samples was higher than the world average value of 59 nGyh^{-1} [2]. The E value for each sample including their average (0.15 ± 0.003 mSvy^{-1}) was less than the permissible limit of 1 mSv per year for safe use [24, 25].

Table 4. Calculated radiological hazard indices of the studied raw material samples from Eastern Uganda

Sample Name	Sample Code	Calculated radiological hazard indices				
		Ra_{eq} ($Bqkg^{-1}$)	H_{ex}	H_{in}	D ($nGyh^{-1}$)	E ($mSvy^{-1}$)
Limestone	TL 1	123.9 ± 3.0	0.3 ± 0.01	0.4 ± 0.01	56.6 ± 1.4	0.07 ± 0.002
	TL 2	113.6 ± 2.3	0.3 ± 0.01	0.3 ± 0.01	52.6 ± 1.1	0.06 ± 0.001
Clay	TC	74.0 ± 2.7	0.2 ± 0.01	0.2 ± 0.01	34.5 ± 1.0	0.04 ± 0.001
Pozzolana	TP	316.7 ± 8.2	0.9 ± 0.02	1.0 ± 0.03	145.3 ± 3.7	0.18 ± 0.005
Average		**157.1 ± 4.7**	**0.4 ± 0.01**	**0.5 ± 0.02**	**72.3 ± 2.1**	**0.09 ± 0.003**

Table 5. Calculated radiological hazard indices of the studied raw material samples from Southwestern Uganda

Sample Name	Sample Code	Calculated radiological hazard indices				
		Ra_{eq} ($Bqkg^{-1}$)	H_{ex}	H_{in}	D ($nGyh^{-1}$)	E ($mSvy^{-1}$)
Limestone	HD	617.6 ± 7.2	1.7 ± 0.02	2.5 ± 0.03	276.2 ± 3.2	0.34 ± 0.004
	HM	197.3 ± 5.2	0.5 ± 0.01	0.7 ± 0.02	90.3 ± 2.3	0.11 ± 0.003
	HSE	216.7 ± 4.9	0.6 ± 0.01	0.8 ± 0.02	98.7 ± 2.2	0.12 ± 0.003
Magnesium Oxide	HHM	170.6 ± 3.7	0.5 ±0.01	0.5 ± 0.01	75.9 ± 1.6	0.09 ± 0.002
Sand	HSS	84.3 ± 2.4	0.2 ± 0.01	0.2 ± 0.01	38.6 ± 1.1	0.05 ± 0.001
	HS	108.6 ± 2.8	0.3 ± 0.01	0.2 ± 0.01	49.5 ± 1.3	0.06 ± 0.002
Clay	HK 1	219.2 ± 4.7	0.6 ± 0.01	0.8 ± 0.02	101.4 ± 2.1	0.12 ± 0.003
	HK 2	252.1 ± 5.3	0.7 ± 0.01	0.9 ± 0.02	116.5 ± 2.4	0.14 ± 0.003
	HC	329.7 ± 7.2	0.9 ± 0.02	1.2 ± 0.03	152.8 ± 3.3	0.19 ± 0.004
Pozzolana	HP	423.3 ± 6.0	1.1 ± 0.02	1.6 ± 0.02	188.1 ± 2.7	0.23 ± 0.003
	HLA	362.1 ± 5.6	1.0 ± 0.02	1.3 ± 0.02	161.6 ± 2.5	0.20 ± 0.003
Average		**271.0 ± 5.2**	**0.7 ± 0.01**	**1.0 ± 0.02**	**122.7 ± 2.3**	**0.15 ± 0.003**

Table 6. Comparison of results obtained in this study with published results from other countries

Country	Average A ($Bqkg^{-1}$)				Ra_{eq} ($Bqkg^{-1}$)	References
	^{238}U	^{226}Ra	^{232}Th	^{40}K		
Uganda	…..	30.2	58.7	557.5	214.6	This study
	…..	94.9	97.1	484.8	271.0	This study
Egypt	134.1	.....	36.0	403.5	239.6	Darwish et al. [28]
Nigeria	323.5	.....	95.9	667.7	.....	Awodugba et al. [29]
Tanzania	.....	28.3	41.5	202.6	103.2	Amasi et al. [1]
Turkey	.....	38.1	92.7	636.6	219.7	Sezgin et al. [30]

The average specific activity concentration and radium equivalent activity values obtained in this study were compared with those obtained by researchers from other countries (see Table 6). From this table, the average specific activity concentration values of ^{226}Ra and ^{232}Th obtained in this study were higher than those determined in Tanzania [1] and Turkey [30]. The average specific activity concentration values of ^{40}K determined in this work were higher than those obtained in Tanzania [1] and Egypt [28] but lower than those reported by Awodugba et al. [29] and Sezgin et al. [30]. The average Ra_{eq} values obtained in this study

were similar to values by Sezgin et al. [30] and Darwish et al. [28] but much higher than the value obtained by Amasi et al. [1] in Tanzania. Generally, from Table 6, both the average specific activity and radium equivalent values varied for all studies. These variations may stem from differences in uranium, thorium, and potassium-40 concentrations in soils, influenced by unique geological formations and geographical conditions across different regions worldwide [4].

4. Conclusions

The study determined the specific activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in cement raw material samples from Eastern and Southwestern Uganda. The specific activity concentration of these radionuclides was high for limestone, clay, and pozzolana samples from Southwestern Uganda compared to similar samples from Eastern Uganda. Generally, the main contributors to the overall average specific activities in the studied samples were clay (Kaolin) and pozzolana. If these raw materials are to be used in cement production, their activity concentration should be carefully monitored.

The radiological safety of the studied samples was assessed by estimating the radium equivalent activities, internal and external hazard indices, and the annual outdoor effective gamma dose values presented in Table 4 and Table 5. The average Ra_{eq} value of cement raw material samples from Southwestern and Eastern Uganda were 271.0 $Bqkg^{-1}$ and 157.1 $Bqkg^{-1}$, respectively. Each of these values was less than the limit of 370 $Bqkg^{-1}$ for building materials. The average H_{ex} and H_{in} values were 0.7 and 1.0 respectively for samples from Southwestern Uganda while for samples from Eastern Uganda, these values were 0.4 and 0.5, respectively. The average E value for samples from Southwestern Uganda was 0.15 $mSvy^{-1}$ whereas that for samples extracted from Eastern Uganda was 0.09 $mSvy^{-1}$. Each of these average annual effective dose values was less than the limit of 1 $mSvy^{-1}$ as per ICRP [24]. Since the average values for radium equivalent activity, external and internal hazard indices, and annual effective doses for the studied limestone, clay, sand, magnesium-oxide, and pozzolana were within the safe recommended limits, we were led to conclude that these samples posed no significant radiological hazard to both miners and the public.

Funding

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

References

[1] A.I. Amasi, K.M. Mtei, I.J. Nathan, P. Jodłowski, C.N. Dinh. Natural Radioactivity in Tanzania Cements and their Raw Materials, Res. J. Environ. Earth Sci. 6 (2014). 469-474. https://doi.org/10.19026/rjees.6.5259.

[2] UNSCEAR. Sources and Effects of Ionizing Radiation Volume I: source, 2000.

[3] EC, Radiation Protection 112: Radiological protection principles concerning the natural radioactivity of building materials, Eur. Comm. (1999). 1-16.

[4] IAEA-TECDOC, Mapping Using Gamma Ray, Encycl. Atmos. Sci. 4 (2003). 1549-1555.

[5] UNSCEAR, UNSCEAR 2008 Report on Sources and Effects of Ionizing Radiation, 2008.

[6] B. Nagudi. Status of Geological Resources in By the Embassy of the Republic of Korea in Uganda, Student Diss. (2011) 1-35.

[7] T. Oates, Lime and limestone, Kirk-Othmer Encycl. Chem. Technol. (2000).

[8] J. Hinton, O. Lyster, J. Katusiime, M. Nanteza, G. Naulo, A. Rolfe, F. Kombo, H. Grundel, K. MacLeod, H. Kyarisiima, et al. Baseline assessment of development minerals in Uganda: volume 1 & 2, (2018).

[9] J.A. Ademola, A.A. Ayeni. Measurement of natural radionuclides and dose assessment of granites from Ondo State, Nigeria. Radioprotection. 45 (2010) 513-521. https://doi.org/10.1051/radiopro/2010046.

[10] O.O. Adewale, I.A. Tubosun, J.O. Ojo. Assessment of terrestrial naturally occurring radioactive Material in soil and mine tailings of Awo and Ede, Osun-State, Nigeria. Ife J. Sci. 17 (2015) 199-209.

[11] S. Şahin Bal. The determination of concentrations of radioisotopes in some granite samples in Turkey and their radiation hazards. Radiat. Eff. Defects Solids. 173 (2018) 353-366. https://doi.org/10.1080/10420150.2018.1462358.

[12] S. Biira, P. Ochom, B. Oryema. Evaluation of radionuclide concentrations and average annual committed effective dose due to medicinal plants and soils commonly consumed by pregnant women in Osukuru, Tororo (Uganda), J. Environ. Radioact. 227 (2021) 106460. https://doi.org/10.1016/j.jenvrad.2020.106460.

[13] WHO, WHO Handbook on Indoor Radon: A Public Health Perspective, World Health Organization, 2009. https://doi.org/10.1080/00207230903556771.

[14] A. Kisolo, E. Barifaijo, T. Strand. Radon monitoring and Dosimetry in Uganda, (2007) 17-27.

[15] A. Mugaiga, E. Jurua, R. Oriada, S. Turyahabwa. Radioactivity levels and dose rates from rocks in selected mining areas and quarries in eastern Uganda. Int. J. Res. Eng. Technol. 5 (2016).

[16] T.E.R. Silver, E. Jurua, R. Oriada, A. Mugaiga, B. Enjiku. Determination of Natural Radioactivity Levels due to Mine Tailings from Selected Mines in Southwestern Uganda. J. Environ. Earth Sci. 6 (2016) 154-163.

[17] IAEA. Guidelines on soil and vegetation sampling for radiological monitoring, Tech. Reports Ser. No. 486 (2019).

[18] IAEA. Measurement of radionuclides in food and the environment, 1989.

[19] J. Beretka, P.J. Mathew. Natural Radıoactıvıty of Australıan Buıldıng Materıals. Industrıal Wastes and By-Products, Heal. Phys. Soc. 48 (1985) 87-95.

[20] D.O. Kpeglo, H. Lawluvi, A. Faanu, A.R. Awudu, P. Deatanyah, S.G. Wotorchi, C.C. Arwui, G. Emi-Reynolds, E.O. Darko. Natural radioactivity and its associated radiological hazards in Ghanaian cement. Res. J. Environ. Earth Sci. 3 (2011) 160-166.

[21] Ş. Turhan. Assessment of the natural radioactivity and radiological hazards in Turkish cement and its raw materials. J. Environ. Radioact. 99 (2008) 404-414.

[22] UNSCEAR. Exposure from Natural Sources of Radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. Report to General Assembly. (1993) 33-90.

[23] R. Krieger. Radioactivity of construction materials. Betonw. Fert. Techn. 47 (1981) 468-473.

[24] ICRP. Resolution of Public Consultation Comments for ICRP Publication 142 Radiological Protection from Naturally Occurring Radioactive Material (NORM) in Industrial Processes. Icrp (2019) 1-5.

[25] IAEA. Radiation Protection of the Public and the Environment, International Atomic Energy Agency, Vienna, 2018.

[26] B.W. Hurley. Natural radioactivity in the geologic environment, Natl. Nucl. Secur. Adm. Nevada Site Off. (2009).

[27] B. Zachary. Technical Meeting on Uranium from Unconventional Resources. Vienna Austria (4-6 November 2009), (2009).

[28] S.M. Darwish, E. Khalifa, M. Al-Abyad, S.M. El-Bahi. Assessment of Environmental Hazards of Natural Radioactivity in Local Cement in Egypt. J. Nucl. Radiat. Phys. 11 (2016) 15-35.

[29] A.O. Awodugba, J.S.A. Adelabu, M.K. Awodele, G.A. Ishola. Gamma ray activity in raw materials and the end product from the West African Portland Cement PLC, Ewekoro, South Western Nigeria. Indoor Built Environ. 16 (2007) 569-572.

[30] N. Sezgin, B. Karakelle, U.E. Temelli, S. Nemlio\uglu. Natural radioactivity and hazard level assessment of cements and cement raw materials. Recycl. Reuse Approaches Better Sustain. (2019) 165-178.