EPJ Nuclear Sci. Technol. **8**, 13 (2022)

https://doi.org/10.1051/epjn/2022012

EPJ Nuclear Sciences & Technologies

Available online at:
https://www.epj-n.org

REGULAR ARTICLE

OPEN ACCESS

Radioactivity and health risk assessments in cement samples commonly used as construction materials in the case of South Gondar Zone, Ethiopia

Tadesse Abate*

Department of Physics, Debre Tabor University, P.O. Box 272, Debre Tabor, Ethiopia

Received: 26 February 2022 / Received in final form: 4 April 2022 / Accepted: 22 June 2022

Abstract. This work deals with the measurement of the radioactivity concentrations from different cement samples collected from the South Gondar Zone, Ethiopia. The measurement of naturally occurring radioisotopes and radiation health impact indices caused by these nuclides in cement samples are indisputable in the dwellings. Specifically, the average concentrations for ^{226}Ra, ^{232}Th and ^{40}K were estimated as 76.53, 81.67, and 407 Bq kg^{-1}, respectively. It was seen that all the measured mean values were greater than the world's limited levels. External and internal hazard indices are calculated as defined by the European Commission from the corresponding concentrations of ^{226}Ra, ^{232}Th and ^{40}K nuclides. Moreover, the natural radionuclides have variety of concentrations which must be caused by the types of raw materials used in the industries for the production of cement.

1 Introduction

Knowing of man about naturally occurring radioactivity concentrations and their distribution in the living areas have become a focus of much attention in assessing the human health indices. Naturally occurring radioactive materials are widely spread in the earth's environment and exist various geological formations such as soils, rocks, plants, water bodies, air, and construction materials [1–3]. Finding of levels for these radioactive elements in building equipment plays the prominent roles in the evaluation of public health indices, as most citizens kill 80% of their time indoors in either of living homes or working offices [4–7]. Naturally occurring radiation sources in construction materials are means of external particle exposure sources in dwellings [3,5–7]. Thus, Uranium, Thorium and their daughter products and ^{40}K are important elements which played the predominant role to contribute a large part of energy dose received by people [8]. The radiation is caused by gamma ray originating from the Uranium, Thorium series and from ^{40}K [8–10].

The average levels of these radionuclides in the natural environment are 35, 30 and 400 Bq/kg, respectively [4,5]. The accepted values in all parts of the world average due to gamma ray from construction materials is equivalent to 0.4 mSv/y [4]. This external radiation exposure caused by those gamma releasing material examining of building equipment with the dose rate modeling. This outdoor dose estimation due to the natural sources is essential as these doses vary depending upon the values of the radioactive materials of ^{226}Ra, ^{232}Th and their decay products and ^{40}K, found in soil and rocks which more depending upon local soil and rock types of each country [13]. Since radium is found everywhere in the environment, its essential daughter nucleus radon is found everywhere with varying concentration and its solid daughter products of ^{218}Po and ^{214}Po which have a chance to distribute themselves over the aerosols in ambient air [3,11–15]. When we take or inhale radon gas or and its daughters along with normal air, most of radon is exhaled, and its decay products got logged to the inner walls and membranes of our respiratory organ and continue constant change due their alpha ionization power. Different cancers and kidney diseases are so influenced by the intake of solid radon daughter products [5,16–18].

Radiological health disturbance caused by radionuclides due to particle energy exposure of a body by the gamma rays and irradiation of the lung cells from inhalation of ^{222}Rn is therefore attracted the world researchers for more investigations [16]. Thus, radiation sources and radioactivity in building materials have got considerable research interest hence humans are exposed to radiation sources at different levels based on natural radioactive minerals present in each region worldwide [19–24]. The purpose of

* e-mail: tadesseabate96@gmail.com

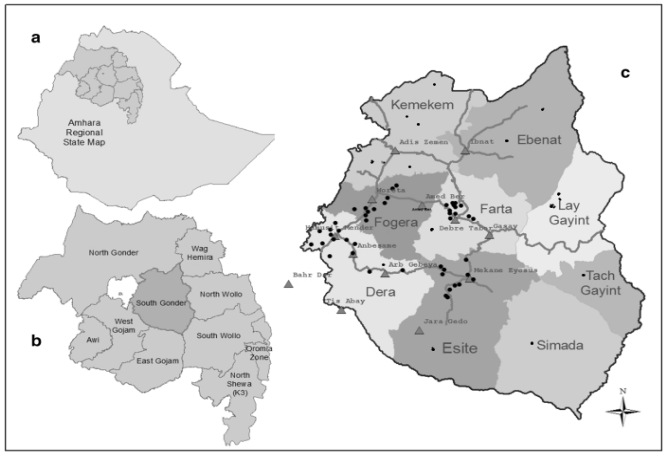

Fig. 1. (a) Map of Ethiopia. (b) Regional map of Amhara. (c) Map of the study sites in Amhara province, Ethiopia [25].

this study is to evaluate the naturally occurring radioactivity values of the commonly used construction material called cement in South Gondar zone in the unit of Bq kg^{-1} and to estimate the health impact caused by these radioactivity.

2 Methodology

2.1 Location of study area

South Gondar is located in Amhara Region, Ethiopia. This zone is named for the city of Gondar, which was the capital of Ethiopia until the mid-19th century, and has often been used as a name for the local province. South Gondar Zone is bordered on the south by East Gojjam, on the southwest by West Gojjam and Bahir Dar, on the west by Lake Tana, on the north by North Gondar, on the northeast by Wag Hemra, on the east by North Wollo, and on the southeast by South Wollo; the Abbay River separates South Gondar from the two Gojjam zones [25].

2.2 Sampling techniques

The main cement stores are located in Debre Tabor (capital of South Gondar Zone), Nefas-Mewucha and Woreta towns. Hence, it is impossible to get all types of cement in one town, we collected the samples from three distribution areas to get representative cement types. In this regard, for this study, thirty cement samples were taken from Dangote, Derba, and National Cement Factory suppliers found in the study area. Approximately, 1 kg of cement sample was collected from the source using cement bags in places where the required sample types are found in the South Gondar (Fig. 1).

2.3 Sample preparation procedure for gamma-ray spectrometry

All the assembled cement samples have been sieved using 400 μm and were dried at a temperature of 100°C about 16 hours until they reached a constant weight to eliminate moisture and humidity. After moisture removal, the samples were cooled in moisture-free atmosphere at room temperature [26]. The dried cement samples were stored into pre-weighting cylindrical plastic container (beaker) of that has a diameter of 6 cm and 7 cm height within the overall volume of 197.82 cm^3. The cylindrical plastic container were hermetically sealed with vinyl tape around its screw neck to prevent possible escape of radon gases. The default method of radon sealing is done by placing the sample container into an aluminum-lined bag and evacuating it using a Henkovac Mini Eco commercial vacuum packaging machine [27]. The closed samples were stored for a minimum period of 30 days to allow for a secular equilibrium between ^{226}Ra, ^{222}Rn and its short-lived decay products before gamma spectrometer measurements.

The measurement was carried-out using p-type high purity Germanium detector which has an efficiency of 48% at 1332 keV and resolution of 1.786 keV with ^{60}Co isotope. The detector was covered by lead at the coat of 10 cm diameter. A used lead shield was with a fixed place at a base and a moving cover to shield the detector from the above to prevent background radiation interactions. The 2 mm thick copper lining was used at the inner side of the shield to protect the detector from unwanted particles produced by the interaction of background with the material around a lead detector. A photo-peak efficiency was determined as a function of the gamma-emission energy, E_γ. These efficiencies ϵ were fitted to the energy values [7].

$$\ln \epsilon = \sum_{i=0}^{4} a_i \left(\frac{E_\gamma}{E_0} \right)^i \tag{1}$$

where a_i is the fitting coefficient, and E_γ is the energy expressed in MeV.

By focussing attention on the energies emitted from the radionuclides of interest ^{214}Pb, ^{214}Bi, ^{228}Ac and ^{40}K efficiency versus density was fitted to an exponential decay function, for each gamma-energy, in order to obtain an empirical relationship between both. This fitting function is [8]:

$$\epsilon(\rho) = \frac{a}{\rho} \left(1 - e^{-b\rho} \right) \tag{2}$$

where a, b are the fitting parameters and ρ is the sample's density expressed in kg/m^3. The activity of ^{226}Ra was measured by the photo-peaks of 609.35 keV and 351.9321 keV from ^{214}Bi and ^{214}Pb radionuclides, respectively. The activity of ^{232}Th was determined through the photo-peak of 238.632 keV, 583.187 keV and 911.204 keV emitted from its short-lived decay products of ^{212}Pb, ^{208}Tl and ^{228}Ac, respectively, while the ^{40}K activity was directly measured using 1460 keV peak of its gamma-ray energy [26,27]. The choice detector has a high efficiency for typical samples, the high purity germanium detector is the Canberra Broad Energy Germanium (CBEGe) which exhibits lower background than typical coaxial detectors since it is more

transparent to high energy gamma from naturally occurring radioisotopes such as ^{40}K and the Thorium series of ^{208}Tl [4]. The function of any detector is to convert radiations' energy into useful electrical signals which can be used, with suitable signal processing.

The correct efficiency calibration requires the correct homogenization of the tracer in the cement, because a heterogeneous distribution would produce an imprecise efficiency determination, that, therefore, would affect negatively the activity values obtained for all the measured samples using such efficiency. Considering the crucial importance of this issue, the homogenization has been verified by measuring the prepared standard for several times and shaking the standard in a strongly way during 10 min before performing each measurement. The standard was measured a total of 13 times, being 2 h the acquisition time, in order to reduce the counting statistical uncertainty below 1% for all the gamma emissions.

The detector was calibrated based on efficiency calibration with a reference geometry: density, volume, radionuclides, summing corrections, and so on. The density, volume and height of sample in the container have been the same as that of the standards (Marinelli beakers used for the standard mixed radionuclide and also for the samples) used for the calibration. ^{241}Am, ^{133}Ba, ^{60}Co and ^{152}Eu IAEA certified radioactive sources were used to determine the efficiency curves. as well the certified activity by IAEA on 01/01/1982 [28]. Generally, the efficiency calibration of the HPGe detector available at the Zentrum für Strahlenschutz und Radiooekologie (ZSR) Hannover University is presented. A detailed information of the standards is available at https:/www.eurostandard.cz/products.html.

The quality assurance of the measurement was carried out periodical efficiency and energy calibration and repeated sample measurement. The counting time of each sample was determined to be 36,000 seconds and repeated twice to get the accepted gamma spectrum with special statistics. To find out the background distribution of radiation spectrum in the living environment around the detector, an empty container was measured in the same manner in the same geometry as we did for the samples. The net peak area of gamma rays for the measured radioisotopes were corrected by using the background spectra [29].

The radioactivity values of terrestrial environment sources of radiations in the counted samples in Bk kg^{-1} were calculated using the relation [5,12]:

$$B = \frac{W}{\epsilon P M t} \tag{3}$$

where W is the net counts of gamma-ray, ϵ is the efficiency of a detector, P is the absolute transition of gamma decay, M is mass of a final prepared sample in kg, and t is a counting time in international unit system.

3 Results and discussions

The radioactivity levels of naturally occurring radioactive materials of ^{226}Ra, ^{232}Th and ^{40}K were evaluated for 30 cement samples from different sources collected from the districts found in South Gondar zone. The counted results of this investigation are given in Table 1 and the radiological health indices for risk assessments are depicted in Table 3.

Table 1. The radioactivity concentrations of natural radionuclides in cement samples in Bq kg^{-1}.

Factory	^{226}Ra	^{232}Th	^{40}K
	40 ± 6.78	101 ± 3.59	510 ± 19.13
	50 ± 4.93	92 ± 1.92	515 ± 20.06
	36 ± 7.53	86 ± 0.80	515 ± 20.06
	70 ± 1.21	101 ± 3.59	360 ± 8.73
Dangote	65 ± 2.14	100 ± 3.40	499 ± 17.08
	98 ± 3.99	99 ± 3.22	480 ± 13.56
	97 ± 3.80	88 ± 1.18	420 ± 2.41
	46 ± 5.67	100 ± 3.40	410 ± 0.56
	98 ± 3.99	92 ± 1.92	490 ± 15.41
	48 ± 5.30	94 ± 2.29	370 ± 6.87
	90 ± 2.50	70 ± 2.17	326 ± 15.04
	90 ± 2.50	76 ± 1.05	310 ± 18.01
	88 ± 2.13	74 ± 1.42	150 ± 47.72
	84 ± 1.39	65 ± 3.10	160 ± 45.87
Derba	66 ± 2.91	64 ± 3.28	260 ± 27.30
	78 ± 0.27	54 ± 5.14	290 ± 21.73
	97 ± 3.80	30 ± 9.60	284 ± 22.84
	98 ± 3.99	47 ± 6.44	289 ± 21.91
	50 ± 4.93	52 ± 5.51	270 ± 25.44
	62 ± 2.70	80 ± 0.66	130 ± 51.44
	58 ± 3.44	82 ± 0.06	484 ± 14.30
	100 ± 4.36	88 ± 1.18	465 ± 10.77
	100 ± 4.36	86 ± 0.80	550 ± 26.55
	92 ± 2.87	79 ± 0.50	540 ± 24.70
National	93 ± 3.06	93 ± 2.10	550 ± 26.55
	93 ± 3.06	88 ± 1.18	520 ± 20.98
	91 ± 2.69	99 ± 3.22	535 ± 23.77
	89 ± 2.32	92 ± 1.92	506 ± 18.38
	95 ± 3.43	94 ± 2.29	500 ± 17.27
	20 ± 10.50	98 ± 3.03	522 ± 21.36

As could be stated in Table 1, the activity concentrations of natural radionuclides of ^{226}Ra, ^{232}Th and ^{40}K ranges from 20 ± 10.50 to 100 ± 4.36, 30 ± 9.60 to 101 ± 3.59, and 130 ± 51.44 to 550 ± 26.55 Bq kg^{-1}, respectively. All the calculated average concentrations are higher than the world's written standard values in the naturally living environment of 35, 30, and 400 Bq kg^{-1}, respectively [4]. The maximum values of ^{226}Ra were observed in the samples which were taken from Derba and National Cement Factories and a minimum value was measured from Dangote Cement industry, while the National Cement and Dangote Cement Factories have recorded the maximum, and Derba Cement Factory has relatively lowest levels of ^{232}Th and ^{40}K. Moreover, it is observed that there are different levels of concentrations for the same type of cement. This may be happened due to the composition of cement type.

Some experimental values presented for reported data of other countries are given for comparison in Table 2.

Table 2. Comparison of mean activity concentrations in Bqkg^{-1} with studied results in cement samples from some selected countries.

Countries	^{226}Ra	^{232}Th	^{40}K	References
Riyadh, Saudi Arabia	21.7	9.8	101.6	[1]
Turkey	52	40	324	[5]
India (2020)	54.59	45.64	1890.28	[15]
India (2016)	35.8	33.2	199.1	[20]
Tamilnadu, India	35.73	37.75	159.83	[21]
Turkey	25	21	2493	[30]
China	119	36	444	[17]
Greece	111	19	244	[31]
Turkey (2017)	33.0	16.7	239.5	[34]
Iraq	31.29	15.97	168.24	[35]
Slovak Republic	11.8	18.4	156.5	[41]
Amhara, Ethiopia	76.53	81.67	407	This study

In this situation, the ^{226}Ra mean activity concentration for cement samples was higher than the concentration for Riyadh–Saudi Arabia, Turkey, India (2020), India (2016), Tamilnadu India, Iraq and Slovak Republic, while less than the concentrations for China and Greece. All the observed values were less than for ^{232}Th activity concentrations which investigated in this study. The mean activity concentration value of ^{40}K was 407 Bq kg^{-1}. This value was lower than for India, Turkey (2493 Bq kg^{-1}), and China, and higher than for all other studies in the table of comparison.

According to our results, the distribution of ^{226}Ra, ^{232}Th and ^{40}K in cements were not constant for all samples. The reason why is because the raw materials which are used by the factories have been taken from different geological places and material types. The non-homogeneous which occurs within exposure to radiation could be defined due to the variety values of radium equivalent activity (Ra_{eq}) in Bq kg^{-1} that was generated from the specific activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K [5]. The radium equivalent activity estimated through the following relation [4,5]

$$Ra_{eq} = B_{Ra} + 1.43B_{Th} + 0.077B_{K} \quad (4)$$

where B_{Ra}, B_{Th} and B_K are the activity concentrations of radium–226, thorium–232 and potassium–40 in Bq kg^{-1}, respectively. The mean Ra_{eq} values are tabulated in Table 3 for the different cement types where they were collected. The minimum value (151.65 ± 13.43 Bq kg^{-1}) was measured for the samples that were taken from Dangote Cement Facory, while the maximum (276.53 ± 9.67 Bq kg^{-1}) value of Ra_{eq} was found in Derba and National Cement Factories cement types, respectively. In general, the average values of Ra_{eq} for the studied cement samples were lower than the limit value of 370 Bq kg^{-1} recommended by Organization for Economic Cooperation and Development [32].

The terrestrial environmental radiation sources of indices dealing with the assessment of the excess gamma radiation arising from construction equipment such as outdoor and indoor hazard indices and gamma radiation indices has been investigated by several investigators [33–39]. For this study, the gamma index (I_γ) was computed using the relation recommended by the European Commission and used by [7,32]

$$I_\gamma = \frac{B_{Ra}}{300\ Bq\ kg^{-1}} + \frac{B_{Th}}{200\ Bq\ kg^{-1}} + \frac{B_K}{3000\ Bq\ kg^{-1}} \quad (5)$$

where B_{Ra}, B_{Th} and B_K are the activity concentrations of radium–226, Thorium–232 and potassium–40, respectively and 300, 200 and 3000 are given in Bq kg^{-1}. The values of I_γ evaluated from the calculated activity concentration of radium–226, Thorium–232 and potassium–40 are presented in Table 3 for different cement types. The values of I_γ for the studied samples varied in the range between 1.053 ± 0.1 to 1.963 ± 0.1 for type of cements which were greater the critical value of unity.

At this particular time, several alpha indices have been recommended to assess the exposure amount due to radon inhalation originating from construction materials [7]. The alpha index, therefore, was calculated by the following relationship

$$I_\alpha = \frac{B_{Ra}}{200\ Bq\ kg^{-1}} \quad (6)$$

where B_{Ra} is the activity value of radium–226 in Bq kg^{-1} that assumed in equilibrium with uranium–238. The proposed widely used in all walks of life for lower and upper level of radium–226 activity concentrations in construction equipment are 100 and 200 Bq kg^{-1}, respectively, as suggested by ICRP [40]. When the materials are used for construct the dwellings or towers, the concentrations of ^{226}Ra never exceeded from the higher recommended value of 200 Bq kg^{-1} for which I_α will have a value equal to unity or greater than 1. While exceeding values results that enough radon could exhalate from these materials which may cause indoor radon value that will exceeded 200 Bq m^{-3} too. In other words, if ^{226}Ra has the concentration less than 200 Bq kg^{-1}, then it resulting indoor radon level which is less than 200 Bq m^{-3}. Thus, such considerations determined the I_α index values which could be less than or greater than unity. For the studied cement samples, I_α index values are given in Table 3 for the various types of cement. The estimated concentrations of I_α for this investigation, ranged from 0.10 to 0.50, with the average of 0.38. Accordingly, our result shows the mean value calculated for I_α index was exactly less than unity.

Mainly, of course, the buildings will cause excessive radiation exposures to the human body due to gamma rays released by lead–214 and bismuth–214 which are progeny of radium–226 and thorium–232 decay chains, respectively and the contribution of ^{40}K to the human body radiation dose is also considered. The intake dose rate in indoor air due to gamma-ray released from radioactivity levels of radium–226 and thorium-232 and potassium-40 was computed using the following formula by applying the factors of ^{226}Ra, ^{232}Th and ^{40}K in

Table 3. Radiological health indices parameters values for different cement types.

S. Code	Ra_{eq}	I_γ	I_α	D $(nGyh^{-1})$	AED $(mSvy^{-1})$	H_{in} $(Bqkg^{-1})$
	151.65 ± 13.43	1.067 ± 0.1	0.200 ± 0.03	68.21 ± 4.500	0.3346	0.5177 ± 0.06
	193.88 ± 5.59	1.053 ± 0.1	0.250 ± 0.03	86.90 ± 1.190	0.4263	0.6587 ± 0.03
	179.77 ± 8.21	1.280 ± 0.1	0.180 ± 0.04	81.30 ± 2.110	0.3988	0.5828 ± 0.04
	164.93 ± 10.96	1.177 ± 0.1	0.350 ± 0.01	76.54 ± 2.980	0.3755	0.6347 ± 0.03
Dangote	218.01 ± 1.11	1.520 ± 0.01	0.325 ± 0.01	97.55 ± 0.860	0.4786	0.7645 ± 0.01
	276.53 ± 9.76	1.963 ± 0.1	0.490 ± 0.02	126.77 ± 6.19	0.6219	1.0118 ± 0.04
	255.18 ± 5.80	1.807 ± 0.04	0.485 ± 0.01	116.98 ± 4.40	0.5738	0.9514 ± 0.03
	171.47 ± 9.75	1.220 ± 0.1	0.325 ± 0.02	80.54 ± 2.251	0.3951	0.7254 ± 0.02
	267.29 ± 8.04	1.900 ± 0.1	0.490 ± 0.02	122.84 ± 5.47	0.6026	0.9868 ± 0.03
	260.91 ± 6.86	1.840 ± 0.1	0.485 ± 0.02	119.08 ± 4.79	0.5842	0.9696 ± 0.03
	232.36 ± 1.56	1.637 ± 0.01	0.450 ± 0.02	106.10 ± 2.42	0.5205	0.8709 ± 0.01
	222.55 ± 0.26	1.567 ± 0.004	0.450 ± 0.02	101.70 ± 1.61	0.4989	0.8444 ± 0.01
	233.09 ± 1.69	1.667 ± 0.01	0.440 ± 0.02	107.88 ± 2.74	0.5292	0.8674 ± 0.01
	216.60 ± 1.37	1.553 ± 0.01	0.420 ± 0.01	100.65 ± 1.41	0.4937	0.8121 ± 0.00
Derba	213.10 ± 2.02	1.5330 ± 0.01	0.400 ± 0.01	99.22 ± 1.160	0.4867	0.7918 ± 0.004
	246.19 ± 4.23	1.767 ± 0.03	0.390 ± 0.01	113.62 ± 3.79	0.5574	0.8757 ± 0.01
	229.04 ± 0.94	1.653 ± 0.01	0.230 ± 0.003	105.04 ± 2.22	0.5153	0.7429 ± 0.01
	233.62 ± 1.79	1.687 ± 0.02	0.240 ± 0.001	107.21 ± 2.62	0.5259	0.7606 ± 0.01
	231.22 ± 1.35	1.667 ± 0.02	0.250 ± 0.03	106.06 ± 2.41	0.5203	0.7596 ± 0.01
	233.41 ± 1.75	1.676 ± 0.02	0.310 ± 0.03	107.21 ± 2.62	0.5259	0.7979 ± 0.003
	239.70 ± 2.92	1.719 ± 0.02	0.290 ± 0.03	109.70 ± 3.07	0.5381	0.8041 ± 0.002
	238.19 ± 2.64	1.857 ± 0.1	0.500 ± 0.02	120.24 ± 5.00	0.5898	0.9770 ± 0.03
	268.19 ± 8.21	1.893 ± 0.1	0.500 ± 0.02	122.54 ± 5.42	0.6011	0.9864 ± 0.03
	224.99 ± 0.19	1.577 ± 0.002	0.460 ± 0.02	$102.41 \pm .174$	0.5024	0.8564 ± 0.01
National	209.71 ± 2.65	1.473 ± 0.02	0.465 ± 0.02	96.05 ± 0.580	0.4712	0.8178 ± 0.001
	192.09 ± 5.92	1.349 ± 0.04	0.465 ± 0.02	88.34 ± 0.830	0.4334	0.7702 ± 0.01
	187.61 ± 6.75	1.319 ± 0.1	0.455 ± 0.02	86.39 ± 1.184	0.4238	0.7527 ± 0.01
	259.52 ± 6.60	1.851 ± 0.1	0.445 ± 0.01	119.35 ± 4.84	0.5855	0.9415 ± 0.02
	267.92 ± 8.16	1.907 ± 0.1	0.475 ± 0.01	123.11 ± 5.52	0.6040	0.9402 ± 0.02
	200.33 ± 4.39	1.461 ± 0.02	0.100 ± 0.1	91.87 ± 0.183	0.4507	0.5950 ± 0.04

dwellings of 0.462, 0.621, and 0.0417, respectively [4].

$$D = 0.462C_{Ra} + 0.621C_{Th} + 0.0417C_K. \quad (7)$$

The factors listed above were used to estimate the overall received dose in air at 1 m to the top from the ground level as recommended by UNSCEAR [8].

It may also be seen that, the inhaled dose in indoor air computed from the computed activities in different cement samples are shown in Table 3 (column 5). The calculated absorbed dose rate for the case of indoor air was found to vary from 68.21 ± 4.50 to 126.77 ± 6.19 $nGyh^{-1}$ with a mean of 103.05 ± 2.87 $nGyh^{-1}$. It was compared that the mean value was higher than the world average recommended value of 84 $nGyh^{-1}$. Results tabulated in Table 3 show that the minimum and the maximum absorbed dose rates in air were delivered by cement samples which have basically higher activity concentrations of radium and thorium, respectively. To evaluate the annual effective dose, it must be taken into account that: (a) the conversion coefficient (0.7 Sv Gy^{-1}) from absorbed dose in air to effective dose and (b) the indoor occupancy factor is 80% for population specially for mothers and children [8,32]. Therefore, the effective dose rate in mSv y^{-1} unit was calculated by the following formula:

$$AED = D \times 8760\ hy^{-1} \times 0.7 \times 0.8 \times 10^{-6}. \quad (8)$$

The measured values of annual effective dose for the selected cement samples were ranged from 0.3346 to 0.6219 $mSvy^{-1}$, with an average value of 0.5055 $mSvy^{-1}$. The corresponding annual effective dose rate from all samples were below the dose criterion of 1 mSv y^{-1}.

The external and internal living environment must qualify for healthy family. In order to keep the safety of the human health from the impact from radon and its progeny which may give rise to indoor radiation exposure, indoor hazard index (H_{in}) was evaluated by using the formula stated by [41].

$$H_{in} = \frac{B_{Ra}}{185} + \frac{B_{Th}}{259} + \frac{B_K}{4810} \leq 1. \quad (9)$$

The values of H_{in} gained are depicted in columns 7 in Table 3. The values are ranged from 0.5177 ± 0.06 to 1.0118 ± 0.04 with the mean of 0.8122 ± 0.02 which are slightly less than unity as required were obtained for H_{in} from all samples except the maximum of 1.0118 ± 0.04. The external values of H_{ex} were also less than unity

according to the contents generated using the equation (10) [41].

$$H_{\text{ex}} = \frac{B_{Ra}}{370} + \frac{B_{Th}}{259} + \frac{B_K}{4810} < 1. \quad (10)$$

4 Conclusions

The levels of the naturally occurring radioisotopes of the ^{226}Ra, ^{232}Th and ^{40}K in the cement samples collected from bags of supplier of the towns found in the South Gondar zone Amhara province, Ethiopia were estimated by using the technique of gamma spectrometry with a high purity germanium detector doped with a very poisonous chemical element thallium. As it may be seen, the radioactivity levels of measured radioisotopes have the mean values of higher activities than the world's average proposed levels. The results may be useful in the assessment of the exposures and the radiation doses due to the natural radioactive material contents in construction material samples. The studied activity concentrations of radium and thorium in the measured samples are greater than twice higher than the world′s mean values of 35 and 30 Bq kg^{-1}, respectively, while the mean concentration of potassium in the samples is slightly greater than the corresponding world typical value of 400 Bq kg^{-1}.

All the measured values given in this study show that the mean radium equivalent activity, gamma index, alpha index, the indoor absorbed dose rate, the annual effective dose rate, and internal dose rate due to emitted gamma radiations in the selected cement samples are 223.97 ± 4.83 Bq kg^{-1}, 1.588 ± 0.04, 0.38 ± 0.02, 103.05 ± 2.87 nGyh^{-1}, 0.5055 ± 0.01 mSvy^{-1}, and 0.8122 ± 0.02 Bq kg^{-1}, respectively. Based on these results, only the indoor absorbed dose rate and the gamma index values are higher than the world's limit values. Hence, a country still has no radiation safety rule guidelines, the results of this study will be used as important database for policy makers for development of radiation protection guide-rule and estimations of the impact of radioactive hazards.

Acknowledgements

We, the authors, would like to thank Debre Tabor University for its financial support. We would also like to thank the community and officials in the study areas for their continuous support during sample collections and preparations.

Conflict of interests

The author declared that no conflicts of interest with respect to the research.

Funding

This research did not receive any specific funding

Data availability statement

We acknowledge that the data we use to support this research can be obtained from the corresponding author at any time with reasonable request.

References

1. H.A. Al-Sewaidan, Natural radioactivity measurements and dose rate assessment of selected ceramic and cement types used in Riyadh, Saudi Arabia, J. King Saud Univ. Sci. **31**, 987–992 (2019)
2. K. Kapanadze, A. Magalashvili, P. Imnadze, Distribution of natural radionuclides in the soils and assessment of radiation hazards in the Khrami Late Variscan crystal massif (Georgia), Heliyon **5**, 1–19 (2019)
3. F.B. Masok, P.L. Masiteng, R.D. Mavunda et al., Measurement of radioactivity concentration in soil samples around phosphate rock storage facility in Richards Bay, South Africa, J. Radiat. Res. Appl. Sci. **11**, 29–36 (2018)
4. P.A. Kumara, P. Mahakumara, A. Jayalath, C.P. Jayalth, Estimating natural radiation exposure from building materials used in Sri Lanka, J. Radiat. Res. Appl. Sci. **11**, 350–354 (2018)
5. N. Damla, U. Cevik, A.I. Kobya et al. Radiation dose estimation and mass attenuation coefficients of cement samples used in Turkey, J. Hazardous Mater. **176**, 644–649 (2010)
6. S. Aközcan, F. Külahci, O. Günay, S. Özden, Radiological risk from activity concentrations of natural radionuclides: cumulative hazard index, J. Radioanal. Nucl. Chem. **78**, 1–18 (2020)
7. European Commission (EC), Radiological protection principles concerning the natural radioactivity of building materials. Directorate – general environment, nuclear safety and civil protection, Radiat. Protect. **112**, 1–16 (1999)
8. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources and effects of ionizing radiation. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation to the General Assembly, UNSCEAR, New York, USA (2000)
9. B.A. Almayahi, A.A. Tajuddin, M.S. Jaafar, Effect of the natural radioactivity concentrations and ^{226}Ra/^{238}U disequilibrium on cancer diseases in Penang, Malaysia, Radiat. Phys. Chem. **81**, 1547–1558 (2012)
10. C. Nuccetelli, F. Leonardi, R. Trevisi, Building material radon emanation and exhalation rate: Need of a shared measurement protocol from the European database analysis, J. Environ. Radioact. **225**, 106438 (2020)
11. V. Kumar, T.V. Ramachandran, R. Prasad, Natural radioactivity of Indian building materials and by-products, Appl. Radiat. Isotopes **51**, 93–96 (1999)
12. M. Faheem, S.A. Mujahid, Matiullah. Assessment of radiological hazards due to the natural radioactivity in soil and building material samples collected from six districts of the Punjab province-Pakistan. Radiat. Measur. **43**, 1443–1447 (2008)
13. N.K. Ahmed, Measurement of natural radioactivity in building materials in Qena city, Upper Egypt, J. Environ. Radioact. **83**, 91–99 (2005)
14. R.R.S. Trevisi, M. D'Alessandro, C. Nuccetelli et al., Natural radioactivity in building materials in the European

Union: a database and an estimate of radiological significance, J. Environ. Radioact. **105**, 11–20 (2012)
15. R. Mehra, S. Kaur, R. Prakash, Optimization of fly ash content in cement and assessment of radiological risk, Indoor Built Environ. **29**, 1–7 (2020)
16. M.T. Kolo, M.U. Khandaker, Y.M. Amin et al., Assessment of health risk due to the exposure of heavy metals in soil around mega coal-fired cement factory in Nigeria, Results Phys. **11**, 755–762 (2018)
17. A. El-Taher, S. Makhluf, A. Nossair, A.S. Abdel Halim, Assessment of natural radioactivity levels and radiation hazards due to cement industry, Appl. Radiat. Isotopes **68**, 169–174 (2010)
18. C.A. Casagrande, W.L. Repette, D. Hotza, Effect of environmental conditions on degradation of NO gases by photocatalytic nanotitania-based cement mortars after long-term hydration, J. Cleaner Product. **274**, 123067 (2020)
19. M. Schuhmacher, J.L. Domingo, J. Garreta, Pollutants emitted by a cement plant: health risks for the population living in the neighborhood, Environ. Res. **95**, 198–206 (2004)
20. N. Sharma, J. Singh, C.S. Esakki, R.M. Tripathi, A study of the natural radioactivity and radon exhalation rate in some cements used in India and its radiological significance, J. Radia. Res. Appl. Sci. **9**, 47–56 (2016)
21. G. Senthilkumar, R. Ravisankar, K. Vanasundari et al., Assessment of radioactivity and the associated hazards in local cement types used in Tamilnadu, India, Radiat. Phys. Chem. **88**, 45–48 (2013)
22. G. Kastiukas, S. Ruan, S. Liang, X. Zhou, Development of precast geopolymer concrete via oven and microwave radiation curing with an environmental assessment, J. Cleaner Product. **255**, 120290 (2020)
23. H.S. Gökce, B.C. Öztürk, Ö.A. Caklr, Natural radioactivity of barite concrete shields containing commonly used supplementary materials, Construct. Build. Mater. **236**, 117569 (2020)
24. D. Otwoma, J.P. Patel, S. Bartilol, A.O. Mustapha, Estimation of annual effective dose and radiation hazards due to natural radionuclidess in Mount, Southestern Kenya, Radiat. Protect. Dosim. **155**, 497–504 (2012)
25. A. Adugna, Amhara national regional state demography and health, USAID, May, 2000 (2021)
26. B.E. Özdis, N.F. Cam, B.C. Öztürk, Assessment of natural radioactivity in cements used as building materials in Turkey, J. Radioanal. Nucl. Chem. **311**, 307–316 (2017)
27. A. Mauring, T. Gäfvert, Radon tightness of different sample sealing methods for gamma spectrometric measurements of ^{226}Ra, Appl. Radiat. Isotopes **81**, 92–95 (2013)
28. International Atomic Energy Agency (IAEA). Basic safety standards for radiation protection, 1982 edition, IAEA, VIENNA, 1982 STI/PUB/607 ISBN 92-0-123982-3
29. K. Aladeniyi, A.M. Arogunjo et al., Evaluation of radiometric standards of major building materials used in dwellings of South-Western Nigeria, Radiat. Phys. Chem. **178**, 109021 (2021)
30. O. Baykara, S. Karatepe, M. Dogru, Assessments of natural radioactivity and radiological hazards in construction materials used in Elazig, Turkey, Radiat. Meas. **46**, 153–158 (2011) doi:10.1016/j.radmeas.2010.08.010
31. H. Papaefthymiou, O. Gouseti, Natural radioactivity and associated radiation hazards in building materials used in Peloponnese, Greece, Radiat. Meas. **43**, 1453–1457 (2008). doi:10.1016/j.radmeas.2008.03.032
32. Organization for Economic Cooperation and Development. Exposure to Radiation from the Natural Radioactivity in Building Materials. Report by a Group of Experts of the OECD, Nuclear Energy Agency (1979)
33. R. Shweikani, M. Kousa, F. Mizban, The use of phosphogypsum in Syrian cement industry: radiation dose to public, Ann. Nucl. Energy **54**, 197–201 (2013)
34. M. Altun, N. Sezgin, S. Nemlioglu et al., Natural radioactivity and hazard-level assessment of Portland cements in Turkey, J. Radioanal. Nucl. Chem. **314**, 941–948 (2017)
35. M.S. Amana, N.J. Jubier, M.J.R. Aldhuhaibat, A.A. Salim, Assessment of radioactivity levels in some cement produced locally in Iraq, Radiat. Detect. Technol. Methods **5**, 633–640 (2021)
36. M.Á. Sanjuán, J.A. Suárez-Navarro, C. Argiz, P. Mora, Assessment of natural radioactivity and radiation hazards owing to coal fly ash and natural Pozzolan Portland cements, J. Radioanal. Nucl. Chem. **325**, 381–390 (2020)
37. M.T. Kolo, M.U. Khandaker, H.K. Shuaibu, Natural radioactivity in soils around mega coal-fired cement factory in Nigeria and its implications on human health and environment, Arab. J. Geosci. **12**, 481 (2019)
38. A. Eštoková, L. Palaščáková, Assessment of natural radioactivity levels of cements and cement composites in the Slovak Republic, Int. J. Environ. Res. Public Health **10**, 7165–7179 (2013)
39. M.A. Etim, K. Babaremu, J. Lazarus, D. Omole, Health risk and environmental assessment of cement production in Nigeria, Atmosphere **12**, 1111 (2021)
40. International Committee on Radiation Protection, Protection against Rn−222 at home and at work. Publication No. 65, Ann. ICRP **23**, Pergamon, Oxford (1994)
41. A.K. Ademola, O.P. Ademola et al., Assessment of natural radioactivity levels in cement samples commonly used for construction in Lagos and Ogun State, Nigeria, Nucl. Radiat. Phys. **102**, 44416–44420 (2017)

Cite this article as: Tadesse Abate. Radioactivity and health risk assessments in cement samples commonly used as construction materials in the case of South Gondar Zone, Ethiopia, EPJ Nuclear Sci. Technol. **8**, 13 (2022)