African Journal of Basic & Applied Sciences 7 (1): 16-25, 2015
ISSN 2079-2034

DOI: 10.5829/idosi.ajbas.2015.7.1.1140

Assessment of Natural Radioactivity and Associated Radiation Hazards in Some Building Materials Used in Kilpenathur, Tiruvannamalai Dist, Tamilnadu, India

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Abstract: The present study aimed to measure the activity concentration of natural radionuclides in the locally used building materials from Kilpenthaur, Tiruvannmalai Dist, Tamilnadu, India was investigated with an aim of evaluating the radiation hazard arising due to the use of these materials in the construction of dwellings. The concentrations of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in four types of building materials have been measured by gamma spectrometry using NaI (Tl) 3" x 3"detector. The estimated radium equivalent activity (Ra_{eq}), criteria formula (C_R), indoor absorbed gamma dose rate (D_R), annual effective dose rate (H_R), annual gonadal dose equivalent (AGDE), activity utilization index (AUI), representative level index (RLI), excess lifetime cancer risk (ELCR), Internal and Extrnal Radiation hazard indeces (H_{in} & H_{ex}) alphaindex ($I\alpha$) and gammaindex ($I\gamma$) were lower than the recommended safe limit and are comparable with results from similar studies conducted in other countries. Therefore, the use of these building material samples under investigation in the construction of dwellings is considered to be safe for inhabitants.

Key words: Building Materials · Natural radioactivity · Gamma Ray spectrometry · Radiological Parameters · Radiation hazards

INTRODUCTION

The natural radioactivity present in the environment is the main source of radiation exposure for humans and constitutes the background radiation level [1]. It is a well-established fact that construction materials contain a trace amount of natural radioactivity, which may contribute significantly towards an increased radiation dose received by human beings. The most commonly encountered radionuclides in the construction materials are ^{226}Ra, ^{232}Th, their decay products and ^{40}K. Therefore, it is important to measure the concentration of these radionuclides in soil and building materials.

Construction materials are derived from both natural sources (e.g. rock and soil) and waste products (e.g. phosphogypsum, alum shale, coal fly ash, oil shale ash, some rare minerals, certain slugs etc.) and also from industry products (e.g. power plants, phosphate fertilizer and oil industry) [2]. Although building materials act as a source of radiation to the inhabitants in their dwellings, they also have the role of a shield against outdoor radiation [3].

The knowledge of natural radioactivity levels is useful in order to set the standards and national guidelines in the light of international recommendations. Due to the increasing social concern, a large number of research groups are engaged in the measurement of natural radioactivity on national as well as worldwide levels [3-10].

In the present work, the concentrations of natural radionuclide were measured in ten building materials samples that are used commonly in Kilpenathur, in the Tiruvannamalai Dist, Tamilnadu, India, by means of gamma-ray spectrometry. The potential radiological

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hazards associated to those materials were assessed by calculating the radium equivalent activity (Ra_{eq}), criteria formula (C_R) indoor absorbed gamma dose rate (D_R), annual effective dose rate (H_R), the external (gamma) (H_{ex}) indexes. The obtained results were compared with the recommended values to assess the radiation hazards to human due to building materials and these results were also compared to the corresponding values of the building materials from different countries.

MATERIALS AND METHODS

Sampling and Preparation: Samples representing 10 commonly used building materials were collected randomly from sites where housing and other buildings were constructed and from the building material suppliers in Kilpenathur, Tiruvannamalai Dist, for the measurement of the specific radioactivity of ^{226}Ra, ^{232}Th and ^{40}K. The samples were properly catalogued and marked according to the origin/location site. After crushing, powdering, coning and quartering, representative samples of maximum grain size 1 mm were dried in an oven at about 110°C until sample weight became constant. These samples were sealed in radon-impermeable plastic containers. The samples were then stored for more than 40 days to bring ^{222}Rn and its short-lived daughter products into equilibrium with ^{226}Ra [10].

Gamma Ray Spectrometric Analysis of Samples: A 3"x3" NaI (Tl) scintillation detector has been used for spectral measurements to enable one to cover the energy spectrum of the naturally occurring radionuclides up to 2.6 MeV (^{208}Tl, a daughter product of ^{232}Th). The detector is shielded by 15 cm thick lead on all sides including top to reduce background due to cosmic ray component by almost 98%. The inner sides of the lead shielding is lined with 2 mm thick Aluminium. Standard sources of the primordial radionuclides obtained from IAEA in the same geometry and having the same density, as that of the prepared soil samples, were used to determine the efficiency of the detector for various energies in the prescribed geometry. The prepared samples were placed on top of the 3"x3" NaI (Tl) detector. Using the gamma ray spectrometer and multichannel analyzer, count spectra were obtained for each of the building material sample. The activity content of the three primordial radionuclides viz., ^{40}K, ^{232}Th and ^{226}Ra are deduced from the count spectra. The region under the peaks corresponding to 1.46 MeV (^{40}K), 1.764 MeV (^{214}Bi) and 2.614 MeV (^{208}Tl) energies were considered to arrive at the radioactivity levels of ^{40}K, ^{226}Ra and ^{232}Th, respectively. The minimum detectable activity (MDA) of each of the three primordial radionuclides was determined from the background radiation spectrum obtained for the same counting time as was done for the soil samples and is estimated as 2.15 Bq kg^{-1} for ^{232}Th, 2.22 Bq kg^{-1} for ^{226}Ra and 8.83 Bq kg^{-1} for ^{40}K. The sealed containers were left for at least 4 weeks (>7 half life's of ^{222}Rn) before counting by gamma ray spectrometry in order to ensure that the daughter products of ^{226}Ra up to ^{210}Pb and ^{228}Th up to ^{208}Pb achieve equilibrium with their respective parent radionuclides. All the building materials were subjected to gamma ray spectral analysis with a counting time of 20,000s.

RESULT AND DISCUSSION

Radionuclide Concentrations: The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K have been measured in four types of building materials in Kilpenathur, Tiruvannamalai Dist, Tamilnadu. Table 1. As it is seen from table 1. The highest mean value of ^{226}Ra is 4.38 (KPC-3) and ^{232}Th is 88.65 (KPSO-1) Bq kg^{-1}, while the samples have the highest value of ^{40}K concentration, 495.77 Bq kg^{-1}. According to this results of Table 1, the maximum concentrations were found for ^{40}K in all types of building materials. The mean values of ^{226}Ra, ^{232}Th and ^{40}K are 1.83 Bq kg^{-1}, 44.37 Bq kg^{-1} and 290.52 Bq kg^{-1} in Table 1. Fig. 1 Shows the Different types of building materials V_S Activity Concentration. As it is observed from table 1, the ranges of mean values of natural radionucides concentration in building materials differ from one country to another depending on the soil and raw materials used for their formation.

Radium Equivalent Activity (Ra_{eq}): The distribution of natural radionuclides in the samples under investigation is not uniform. Therefore, a common radiological index has been introduced to evaluate the actual activity level of ^{226}Ra, ^{232}Th and ^{40}K in the samples and the radiation hazards associated with these radionuclides. This index is usually known as radium equivalent activity[11].

$$Ra_{eq}\ (\text{Bq kg}^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077A_K \qquad (1)$$

where A_{Ra}, A_{Th} and A_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively. In the definition, it is assumed that 10 Bq kg^{-1} of ^{226}Ra, 7 Bq kg^{-1} of ^{232}Th and 130 Bq kg^{-1} of ^{40}K produce an equal gamma-ray dose [12,13].

Table 1: Activity concentration (Bq kg^{-1}), Radium equivalent (R_{eq}), Criterion formula (CR), Absorbed dose rate (D_R), Annual effective dose rate (H_R), Annual gonadal dose equivalent (AGDE), Activity utilization index (AUI) in different types of building materials of Killpenathur, Tiruvannamalai, Dist, Tamilnadu, India

S.No	Materials	Sample ID	Activity Conentration (Bq kg^{-1}) ^{226}Ra	^{232}Th	^{40}K	Ra_{eq} (Bq kg^{-1})	Criteria formula (CR)	Absorbed dose rate (D_R)(nGyh^{-1})	Annual Effective dose rate (H_R)(mSv y^{-1})	AGDE (μSv y^{-1})	AUI
1	Brick	KPB-1	0.00	43.02	249.31	80.72	0.109	67.27	0.083	258.11	0.540
2		KPB-2	4.34	47.42	303.28	95.50	0.129	80.42	0.099	306.86	0.638
3		KPB-3	0.00	26.25	152.08	49.25	0.066	41.04	0.050	157.48	0.330
4		KPB-4	3.34	48.21	412.16	104.02	0.140	89.08	0.110	341.26	0.648
5	Clay	KPC-1	3.87	30.59	247.40	66.66	0.090	57.00	0.070	217.51	0.426
6		KPC-2	0.00	32.87	252.10	66.42	0.089	56.33	0.069	216.56	0.418
7		KPC-3	4.38	46.21	315.28	94.74	0.128	80.08	0.099	305.69	0.625
8		KPC-4	2.33	41.87	299.91	85.30	0.115	72.19	0.089	276.39	0.552
9	Sand	KPSO-1	0.00	88.65	495.77	164.94	0.222	137.18	0.169	526.23	1.112
10	Soil	KPSA-1	0.00	38.64	177.91	68.95	0.093	56.74	0.070	217.38	0.482
	Average		1.83	44.37	290.52	87.65	0.118	73.73	0.091	282.34	0.577

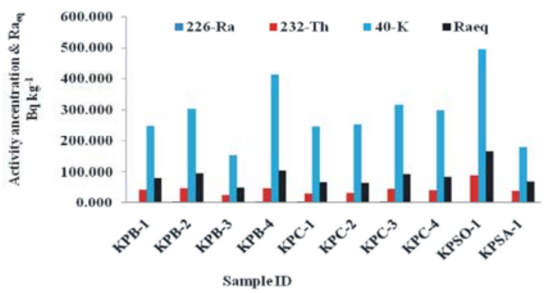

Fig. 1: Different types of locations Vs Activity Concentration and Raeq (Bg kg^{-1})

The values of calculated Ra_{eq} for building materials are shown in the seventh column of Table 1. The calculated Ra_{eq} values range from 49.25 (KPB-3) to 164.94 (KPSO-1) Bq kg^{-1} with an average of 87.65 Bq kg^{-1}. All the values of Ra_{eq} in the studied samples are found to be lower than the criterion limit of 370 Bq kg^{-1} [14]. The results of this study show that the average value of Ra_{eq} obtained for the building materials is 87.65 Bq kg^{-1} which is less than the recommended value (370 Bq kg^{-1}) and the studied building materials do not pose a radiological hazard when used for construction of buildings. Table 3 lists the comparison between activity concentrations and radium equivalents (Bq kg^{-1}) in different type of building materials in different areas of the world. Fig. 1 Shows the Different types of building materials V_S Radium equivalent activity in Kilpenathur, Tiruvannamalai Dist, Tamilnadu, India.

Criteria Formula (CR): Based on models suggested by Krisiuk and Stranden, a value of 1.5 mGy was obtained by Kreiger, when evaluating the annual external radiation dose inside dwellings constructed of building materials with a Ra_{eq} value of 370 Bqkg^{-1}. These authors later corrected their calculations by taking into consideration a wall of finite thickness and applying a weighing factor of 0.7 to account for the presence of windows and doors [15]. Their results can be used as a criterion to limit the annual radiation dose from building materials based on the formula

$$CR = \frac{A_{Ra}}{740 Bq/kg} + \frac{A_{Th}}{520 Bq/kg} + \frac{A_K}{9620 Bq/kg} \quad (2)$$

whereA_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in building materials in units of Bq kg^{-1}. Calculating the sum of the three quotients, the values for the samples in the present study ranged from 0.066 (KPB-3) to 0.222 (KPSO-1) with an average of 0.118 (Table 1). The average value (0.118) of the studied samples is less than the recommended value (<1). This indicates that gamma activity in building materials do not exceed the proposed criterion level. The Fig. 2 Shows the Different types of building materials V_S Criterion formula in Kilpenathur, Tiruvannamalai Dist, Tamilnadu.

Estimation of the Absorbed Gamma Dose Rate (D_R): The mean values of gamma dose rate in air at the distance of 1 m from the ground were estimated using Eq (3) for different kinds of building materials.

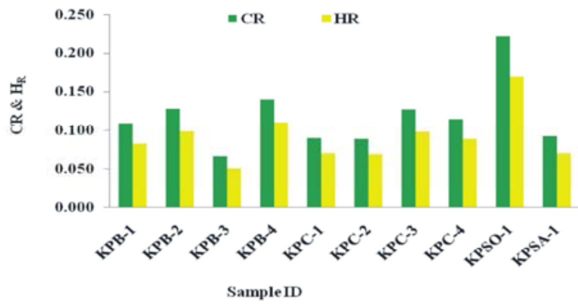

Fig. 2: Different types of locations VsCR and H_R (mSv y^{-1})

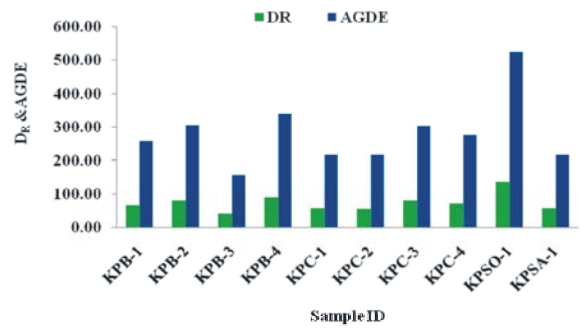

Fig. 3: Different types of locations Vs D_R (nGy h^{-1}) and AGDE (μSv y^{-1})

$$D_R(nGyh^{-1}) = 0.92A_{Ra} + 1.1A_{Th} + 0.0807A_K \quad (3)$$

whereA_{Ra} is the activity concentration of ^{226}Ra, A_{Th} is the activity concentration of ^{232}Th and A_K is the activity concentration of ^{40}K in units of Bq kg^{-1}. The maximum gamma dose rate was 137.18 $nGyh^{-1}$ in KPSO-1, while the minimum value was found for KPB-3 about 41.04 $nGyh^{-1}$ and also the average value of absorbed gamma does rate is 73.73 $nGyh^{-1}$. The estimated mean value of D_R in the studied samples is 73.73 $nGyh^{-1}$ which is lower than the world average indoor absorbed does rate of 84$nGyh^{-1}$. Fig. 3 Different types of building materials Vs Absorbed gamma does rate with in Kilpenathur, Tiruvannamalai Dist, Tamilnadu.

Annual Effective Dose Rate (H_R): To estimate the annual effective dose rate, it is necessary to use the conversion coefficient from the absorbed dose in air to the effective dose (0.7 $SvGy^{-1}$) and the outdoor occupancy factor (0.2 $SvGy^{-1}$) proposed by UNSCEAR (2000) [16]. Therefore, the effective dose rate is determined as follows:

H_R (mSv y^{-1}) = D_R (nGy h^{-1}) × 24 h × 365.25 d × 0.2 (out-door occupancy factor) × 0.7 Sv Gy^{-1} (conversion factor)×10^{-6}

$$H_R = D_R \times 8766 \times 0.2 \times 0.7 \times 10^{-6} = D_R \times 0.00123 \quad (4)$$

where D_R (nGy h^{-1}) is given by Eq. (3). The estimated H_R values for all the studied building materials ranges from 0.05 (KPB-3) to 0.169 (KPSO-1) mSv y^{-1} (Table 1), with mean value of the annual effective dose rate of 0.091 $mSvy^{-1}$ which is less than the permissible limit. Fig. 2 shows the different types of building materials Vs Annual effective dose rate in Kilpenathur, Tiruvannamalai Dist.

Annual Gonadal Dose Equivalent (AGDE): In the same context, the activities of bone marrow and bone surface cells are considered to be organs of interest by UNSCEAR (1988) [17]. Therefore, the annual gonadal dose equivalent (AGDE) arising from the specific activities of ^{226}Ra, ^{232}Th and ^{40}K was calculated using the following formula [18]:

$$AGDE\ (mSv\ y^{-1}) = 3.09\ A_{ra} + 4.18\ A_{th} + 0.31A_K \quad (5)$$

The AGDE values are presented in Table 1. The average values do not generally exceed the permissible recommended limits, indicating that the hazardous effects of the radiation are negligible. However, the overall average AGDE value is found to be 282.34 $mSvy^{-1}$. In the literature, the average AGDE value for the Eastern Desert of Egypt was found to be 2398 $mSvy^{-1}$ [19]. This value is higher than our results. Fig. 3 shows the Different types of building materials Vs Annual gonadal dose equivalent values.

Activity Utilization Index (AUI): Building materials act as sources of radiation and also as shields against outdoor radiation [20]. In massive houses constructed of various building materials, such as stone, bricks, concrete or granite, the factor that most strongly affects the indoor absorbed dose is the activity concentrations of natural radionuclides in those materials, while the radiation emitted by outdoor sources is efficiently absorbed by the walls. Consequently, dose rates in indoor air will be elevated according to the concentrations of naturally occurring radionuclides in the construction materials that are used. To facilitate the calculation of dose rates in air from different combinations of the three radionuclides in building materials and by applying the appropriate conversion factors, an activity utilization index (AUI) can be constructed, as given by the following expression:

$$AUI = \frac{A_{Ra}}{50Bq/kg} f_U + \frac{A_{Th}}{50Bq/kg} f_{Th} + \frac{A_k}{500Bq/kg} f_K \qquad (6)$$

where A_{Th}, A_{ra} and A_K are the actual values of the activities per unit mass ($Bqkg^{-1}$) of ^{232}Th, ^{226}Ra and ^{40}K, respectively, in the considered building materials; f_{Th}, f_{Ra} and f_K are the fractional contributions to the total dose rate in air attributed to gamma radiation from the actual concentrations of these radionuclides. In the NEA-OECD (1979) [14] report, the typical activities per unit mass of ^{232}Th, ^{226}Ra and ^{40}K in building materials, A_{Th}, A_{Ra} and A_K, are reported to be 50, 50 and 500 $Bqkg^{-1}$, respectively. The activity utilization index is weighted for the mass proportion of the building materials in a house by multiplying the characteristic activity associated with each material by a factor wm, which represents the fractional usage of those materials in the dwelling. To be more specific, full mass utilization (*wm*=1) of a given material implies that all building materials used in a model masonry house are composed of this specific material. Half mass utilization (*wm*=0.5) means that 50% of the masonry mass is composed of the material considered and so on. For full mass utilization of a model masonry house (A_{Th}=A_{Ra}=50 $Bqkg^{-1}$ and A_K=500 $Bqkg^{-1}$), the activity utilization index is unity by definition and is deemed to imply a dose rate of 80 $nGyh^{-1}$[20]. The studied building materials can be evaluated in terms of whether they can be used for building construction by calculating the activity utilization index. The activity utilization index of the building materials was calculated using Eq. (6). The calculated values (Table 1) range from 0.33 (KPB-3) to 1.112 (KPB-4) with an average of 0.577. These values satisfy AUI < 2, which corresponds to an annual effective dose ≤ 0.3 mSv y^{-1}[21]. This indicates that these materials can be safely used for the construction of buildings. Fig. 4 Shows the various types of building materials VsActivity utilization index values.

Representative Level Index (RLI): To estimate the level of gamma radioactivity associated with different concentrations of certain specific radionuclides, known as the representative level index [14, 22-24], the formula is given as:

$$RLI = \frac{1}{150 A_{Ra}} + \frac{1}{100 A_{Th}} + \frac{1}{1500 A_K} \qquad (7)$$

where A_{Ra}, A_{th} and A_K are the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in units of $Bqkg^{-1}$. The calculated RLI values for the samples under investigation are given in Table 2. The representative level index varies from 0.364 to 1.217 with an average of 0.656. It is clear that this average value does not exceed the upper limit for the RLI, which is unity [25]. Therefore, the above results show that these building materials present no radiation hazard and are not harmful to human beings. Fig. 4 Shows the Different types of building materials Vs Representative level index.

Excess Lifetime Cancer Risk (ELCR): Another radiological parameter, the excess lifetime cancer risk (ELCR), was calculated using the following equation [26] and is presented in Table 2:

$$ELCR = HR \times DL \times RF \qquad (8)$$

where HR, DL and RF are the annual effective dose equivalent, duration of life (70 years) and risk factor (0.05 Sv^{-1}), respectively. The risk factor is defined as the fatal cancer risk per sievert. For stochastic effects, the ICRP 60 uses a value of 0.05 for the public [26]. The calculated range of ELCR is 0.177×10^{-3} (KPB-3) 0.591×10^{-3} (KPSO-1) with an average of 0.317×10^{-3} for five types of building materials. The average ELCR values are slightly higher than the world average (0.29×10^{-3}) [16]. Fig. 4 Shows Different types of building materials Vs Excess lifetime cancer risk values.

Radiation Hazard Indices: Beretka and Mathew (1985) [11] defined two indices that represent (i) the internal radiation hazard, H_{in} (ii) the external radiation hazard, H_{ex}, which are discussed in this section. The 10^{th} and 11^{th} columns of Table 2 show the internal radiation hazards and external radiation hazards.

Table 2: Activity concentration (Bq kg^{-1}), Radium equivalent (R_{eq}), Representative level index (RLI), Excess lifetime cancer (ELCR), Radiation hazards (H_{in} and H_{ex}), Alpha index(Iα), Gammaindex(Iγ) in different types of building materials of Killpenathur, Tiruvannamalai, Dist, Tamilnadu, India

S. No	Materials	Sample ID	Activity Conentration (Bq kg^{-1}) ^{226}Ra	^{232}Th	^{40}K	Ra_{eq} (Bqkg^{-1})	RLI	ELCR ×10^{-3}	H_{in}	H_{ex}	Alpha Index (I*a*)	Gamma Index (Iγ)
1	Brick	KPB-1	0.00	43.02	249.31	80.72	0.596	0.290	0.218	0.218	0.000	0.298
2		KPB-2	4.34	47.42	303.28	95.50	0.720	0.346	0.270	0.258	0.022	0.353
3		KPB-3	0.00	26.25	152.08	49.25	0.364	0.177	0.133	0.133	0.000	0.182
4		KPB-4	3.34	48.21	412.16	104.02	0.790	0.383	0.290	0.281	0.017	0.390
5	Clay	KPC-1	3.87	30.59	247.40	66.66	0.510	0.245	0.190	0.180	0.019	0.248
6		KPC-2	0.00	32.87	252.10	66.42	0.497	0.242	0.179	0.179	0.000	0.248
7		KPC-3	4.38	46.21	315.28	94.74	0.716	0.345	0.268	0.256	0.022	0.351
8		KPC-4	2.33	41.87	299.91	85.30	0.642	0.311	0.237	0.230	0.012	0.317
9	Sand	KPSO-1	0.00	88.65	495.77	164.94	1.217	0.591	0.445	0.445	0.000	0.609
10	Soil	KPSA-1	0.00	38.64	177.91	68.95	0.505	0.244	0.186	0.186	0.000	0.253
	Average		1.83	44.37	290.52	87.65	0.656	0.317	0.242	0.237	0.009	0.325

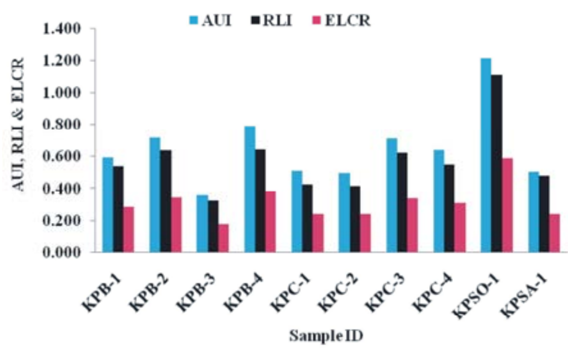

Fig. 4: Different types of locations VsAUI, RLI (Bq kg^{-1}) & ELCR (× 10^{-3})

Internal Radiation Hazard (H_{in}): In addition to the external radiation hazard they pose radon and its short-lived daughters are also hazardous to the respiratory organs. The internal exposure caused by radon and its daughter products is quantified by the internal hazard index H_{in}, which has been defined as shown below:

$$H_{in} = \frac{A_{Ra}}{185 Bq/kg} + \frac{A_{Th}}{259 Bq/kg} + \frac{A_k}{4810 Bq/kg} \quad (9)$$

The internal hazard index is defined to reduce the acceptable maximum concentration of ^{226}Ra to half the value appropriate to external exposure alone. For the safe use of materials in the construction of dwellings, the following criterion was proposed by Krieger (1981) [27]:

$$H_{in} \leq 1 \quad (10)$$

The mean value of H_{in} is determined to be 0.241, which is <1, indicating that the internal hazard is below the critical value and it indicates that the materials are free from radiation hazards. Fig. 5 shows the Different types of building materials and Internal radiation hazard (H_{in}).

External Radiation Hazard (H_{ex}): The external hazard index is another criterion to assess the radiological suitability of a material. Beretka and Mathew introduced a hazard index for the external gamma radiation dose from building materials as given below [11].

$$H_{ex} = \frac{A_{Ra}}{370 Bq/kg} + \frac{A_{Th}}{259 Bq/kg} + \frac{A_k}{4810 Bq/kg} \leq 1 \quad (11)$$

whereA_{Ra}, A_{Th} and A_K are the activities of ^{226}Ra, ^{232}Th and ^{40}K in Bq Kg^{-1}. The values of the indices should be <1. It is observed from table 2, all the values of H_{ex} are below the criterion value (<1) and indicates the materials are free from the radiation hazards. Fig. 5 Shows the Different types of building materials Vs External radiation hazard (Hex).

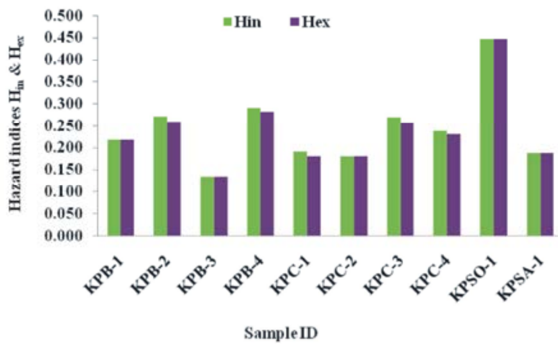

Fig. 5: Different types of locations Vs Radiation Hazard Indices (H_{in}& H_{ex})

Table 3: Comparison of activity concentration and radium equivalents (Bqkg^{-1}) in some type of building materials in different areas of the world.

S.no	Country	Material	Activity concentration (Bq kg^{-1}) ^{226}Ra	^{232}Th	^{40}K	Ra_{eq} Bq kg^{-1}	Reference
1	China	Brick	41	52	717	170.56	[34]
		Soil	44	47	593.1	156.87	[34]
		Sand	39.4	47.2	573	151.01	[35]
		Clay	41	52	717	170.56	[34]
2	Germany	Brick	59	67	673	207	[14]
		Soil	-	-	-	-	-
		Sand	-	-	-	-	-
		Clay	59	67	673	207	[14]
3	Pakistan	Brick	45	61	692	185.51	[36]
		Soil	46.5	60.8	698.6	187.23	[37]
		Sand	21.5	31.9	520	107.15	[36]
		Clay	45	61	692	185.51	[36]
3	Sweden	Brick	96	127	962	352	[14]
		Soil	-	-	-	-	-
		Sand	-	-	-	-	-
		Clay	96	127	962	352	[14]
5	Egypt	Brick	24	24.1	258	78.32	[38]
		Soil	13	6	433	54.92	[39]
		Sand	9.2	3.3	47.3	17.56	[40]
		Clay	24	24.1	258	78.32	[38]
6	India (Tiruvannamalai /Tamilnadu)	Brick	5	23	374	61	[41]
		Soil	6	26	501	82.25	[41]
		Sand	11	130	297	221	[41]
		Clay	4.57	25.14	388.71	71	[41]
6	Present Work	Brick	3.84	41.22	279.20	80.41	-
		Soil	BDL	88.65	497.77	161.47	
		Sand	BDL	38.64	177.91	67.71	
		Clay	3.52	37.88	278.67	76.32	

Alpha Index (Iα): The alpha index was developed as an assessment of the excess alpha radiation exposure caused by inhalation originating from building materials. The alpha index (Iα) is determined by the following formula [28].

$$I_{\alpha} = \frac{C_{Ra}}{200 Bq/kg} \qquad (12)$$

where C_{Ra} is the ^{226}Ra activity concentration (Bq kg^{-1}) in the building materials. When the ^{226}Ra activity concentration of a building material exceeds a value of 200 Bqkg^{-1}, it is possible that the radon out gassing from this material could cause an indoor radon concentration in excess of 200 Bq m^{-3}. In contrast, when the ^{226}Ra activity concentration is below 100 Bq kg^{-1}, it is unlikely that the radon exhalation from the building materials could

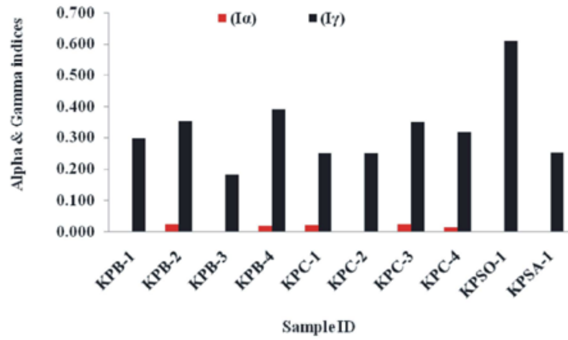

Fig. 6: Different types of locations Vs Alpha and Gamma Index

cause indoor radon concentrations in excess of exceeding 200 Bq m^{-3}[29]. The recommended exemption level and recommended upper level for the ^{226}Ra activity concentration in building materials are 100 Bq kg^{-1} and 200 Bq kg^{-1}, respectively, in building materials as suggested by the Radiation Protection Authorities in Denmark, Finland, Iceland, Norway and Sweden [29]. This upper level is in agreement with the action level given by the ICRP in Publication 65 (1994) [30] and by the European Commission (EC, 1990) [31]. As can be observed from Table 2, the values of the alpha index in the studied samples are below the recommended limit, i.e., $I_\alpha<1$, Therefore, radon inhalation from the brick, clay, soil, and sand cement samples under investigation is not so large as to restrict the use of these materials in construction. Fig. 6 Shows the Different types of buildingmaterials VsAlpha index (Iα).

Gamma Index (Iγ): Another radiation hazard index, the gamma activity concentration index, Iγ, has been defined by the European Commission (EC) and Righi and Bruzzi (2006) [28] and is given as:

$$I\gamma = \frac{C_{Ra}}{300Bq/kg} + \frac{C_{Th}}{200Bq/kg} + \frac{C_K}{3000Bq/kg} \quad (13)$$

The index Iγ is correlated with the annual dose rate attributed to excess external gamma radiation caused by superficial material. Values of $I\gamma \leq 2$ correspond to a dose rate criterion of 0.3 $mSvy^{-1}$, where as $2<I\gamma>6$ corresponds to a criterion of 1 $mSvy^{-1}$ [31, 32]. Thus, the activity concentration index should be used only as a screening tool for identifying materials that might be of concern when used as construction materials; although materials with $I\gamma>6$ should be avoided, these values correspond to dose rates higher than 1 mSv y^{-1} [33], which is the highest dose rate value recommended for the population [16]. The European Commission (EC, 1999) [33] suggests that building materials should be exempted from all restrictions concerning their radioactivity provided that the excess gamma radiation originating from them does not increase the annual effective dose to a member of the public by more than 0.3 mSv [32]. Dose rates higher than 1 $mSvy^{-1}$ should be permitted only in some very exceptional cases in which the materials are used locally. The index Iγ was estimated using Eq. (13). The distribution of the values of Iγ for the building materials analyzed in this work is presented in Table 2. The gamma index Iγ for the building materials varies between 0.182 (KPB-3) and 0.609 (KPSO-1) with an average of 0.325. Therefore, the annual effective dose delivered by the building materials is smaller than the annual effective dose constraint of 1 $mSvy^{-1}$. Therefore, these building materials can be exempted from all restrictions concerning radioactivity. Fig. 6 Shows the Different types of building materials Vs Gmma index (Iγ).

CONCLUSION

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K have been measured in four types of building material samples collected from Kilpenathur, in the Tiruvannamali Dist, Tamilnadu, India using gamma ray spectrometry. The results show that the activity concentrations in all the samples were within the acceptable limits. The radium equivalent activity was well below the defined limit of 370 Bq kg^{-1}. The calculations of criteria formula (C_R), indoor absorbed gamma dose rate (D_R), annual effective dose rate (H_R) and the external and internal hazard indices show well below the recommended safety limits. In view of the above facts, these materials are quite safe to be used as building materials. The future work plans to collect more number of samples in the region and analysed with statisical approach.

ACKNOWLEDGEMENT

One of the auther (R. Ravisankar) wishes to express his high gratitude to Dr. B. Venkatraman AD, RSEG, IGCAR for giving his permission to use the nuclear counting facility in RSD and also Mr. R. Mathiarasu, Scientific Officer, RSD, IGCAR, Kalpakam, India for his technical help in counting the samples. Our special thanks to Dr. M. T. Jose, Head, RSD, IGCAR for his keen help, constant encouragements in Gamma ray spectroscopic measurements.

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