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A Comparative Study of Natural Radioactivity and Associated Radiological Hazards of Imported Sanitary Ware Products Sold in Kenya

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ABSTRACT

Natural radioisotopes are present in all ceramic products used in building construction at varying rates. The primary source of outdoor radiation that residents of homes or workplaces are exposed to is these radioisotopes. Determining the radiation levels of ceramic items used in buildings is crucial. In this investigation, Thallium doped sodium iodide detector NaI(Ti) was used to measure the natural radioactivity levels (226Ra, 232Th, and 40K) in twelve ceramic sanitary ware products manufactured in India, China and Uganda imported and used in Kenya. For the studied samples, the average activity concentrations of 226Ra, 232Th, and 40K radionuclides were 19.5±0.99Bq/kg, 89.75±4.49Bq/kg and 405.75±20.29Bq/kg for 226Ra, 232Th and 40K respectively. With the exception of the average 232Th concentration of studied samples, these results are lower than the global average values (50, 50, and 500 Bq/kg).Values for radium equivalent activity (Raeq), gamma index (Iγ), external hazard index (Hex), internal hazard index (HIn), absorbed dose rate (ADR), annual effective dose (AED), and excess lifetime cancer risk (ELCR) were also computed in order to assess the radiological risks resulting from naturally occurring radionuclides of the ceramic sanitary ware samples under examination. The mean of the radioactive hazard parameters (Raeq, Iγ, Hex, HIn ,D, and AEDE,) computed for every sample of ceramic sanitary equipment was discovered to be below the upper bounds suggested by global organization safe for ELCR which registered slightly higher values.

KEYWORDS

Natural radioisotopes; ceramic sanitary ware; Thallium doped sodium iodide detector; radioactive hazard parameters

1. INTRODUCTION

Buildings are fitted with ceramic sanitary ware products in bathrooms, sinks and toilets. During production, the ceramic products are made from a mixture of zinc oxide, feldspar, kaolin and zircon as an opacifying constituent [1]. The glaze zircon shows elevated concentration of natural radioactivity significantly higher than the permissible limits [2]. It has been observed that high or elevated levels of radioactivity in construction materials increases internal and external exposure [3].

Most sanitary ware is made of ceramic. The sanitary ware market in the world has a trading volume of approximately 9.1 Billion Euros [4]. The sanitary ware market is expected to witness a compounded growth and high usage as attributed to changing lifestyles of people with regard to home décor products. Kenya having an estimated 12.1 million households with an annual demand for 250,000 housing units that statistically translates into more than double the number of sanitation elements required annually due to increased housing demand. This makes sanitary wares to be used at an increased rate by Kenyans and hence the need to determine natural radioactivity associated with use of sanitary ware as décor in buildings.

The fact that sanitary ware elements are fundamental building materials, an investigation of their radiological impact on members of the public is necessary with emphasis on gamma radiation and inhalation of Radon released from the product as main exposure pathway of the radionuclides [5]. Research on ceramic tiles for flooring or walling been done and documented [6] but little has been done on ceramic sanitary ware from different countries. Therefore, the general objective of this study was to compare the natural radioactivity levels (226Ra, 232 Th and 40K) in ceramic sanitary ware products from different countries that are sold commercially in Kenya. The research also investigated the radiological hazards associated to the use of the ceramic sanitary ware products.

2. MATERIALS AND METHODS

2.1 Collection of Samples

Ceramic sanitary ware products are produced from different countries. Pieces of closet and sink samples as end user product for building and sanitation elements were purchased from the different local hardware stores around Kenyan towns market based on countries of origin and catalogued as country A, B and C. Twelve (12) samples were collected and labeled according to the country of origin.

2.2 Preparation of samples

The ceramic sanitary ware collected from the large distributing hardware stores were broken into small size with a sledge hammer. Then the small pieces were reduced further by use of a grinding mill for a triturate .The ground samples were then sieved through a fine 0.6 mm mesh size to obtain a homogenized particle size and each sample with a mass of about 300g. They were finally filled in uncontaminated sealed empty uniform sized cylindrical standard 1000ml plastic containers of uniform size to avoid escape of gaseous radon at airtight conditions. They were stored for four weeks (28 Days) before analysis at airtight conditions to obtain secular equilibrium between radium and its short-lived decay products. The sanitary ware labeled samples were taken for measurement and the levels of radiation present were determined.

2.3 Determination of radioactivity

Natural radioactivity levels (^{226}Ra, ^{232} Th and ^{40}K) in sanitary ware products were determined using a thallium doped sodium iodide detector a NaI(Tl). It consists of a shielded of NaI(Tl) detector. The system also includes an Oxford PCA-P multichannel analyzer (MCA) card and its software for spectral data acquisition and analysis. The PCA-P comprises of a high voltage supply, a charge sensitive pre-amplifier, a shaping amplifier, 80 MHz Wilkinson analogue to digital converter (ADC) with multichannel analyzer (MCA).

The gamma spectrometry detector was calibrated before it was used for analysis. The energy peaks of 662 Kev of ^{137}Cs, 1170 Kev and 1330 Kev of ^{60}Co were used to calibrate the spectrometer. The background radioactivity distribution in the environment around the detector was determined by counting a plastic container filled with distilled water in the same manner and in the same geometry as the samples. The background measurement was repeated at regular intervals for quality control. The background radiation was subtracted from each of the recorded spectrum [7]. A standard IAEA certified samples of ^{238}U, ^{232}Th and ^{40}K were used. The peak corresponding to 1460 Kev (^{40}K) for ^{40}K, 1765 Kev (Bi-214) for ^{238}U and 2615 Kev (Tl-208) for ^{232}Th [8] were considered in arriving at the activity levels.

A time of 30000 seconds for acquiring data for each sample and distilled water for determining background radiation was set. The reference sample was also analyzed. From the counting spectra, the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K was determined. The activity concentrations of radionuclides in the samples were determined using Equation (1) [9].

$$A_C = \frac{C}{\varepsilon m p_{\gamma t}} \qquad (1)$$

Where C is the count (area), Ɛ is the detector efficiency, p_γ is the transition probability, m is the mass in (kg) and t is the time taken in seconds (s).

2.4 Assessment of the Radiological Hazards

To evaluate the radiological effects of ceramic and porcelain sanitation elements containing different levels of ^{226}Ra, ^{232}Th and ^{40}K, one of the determined values used was the (Ra_{eq}) value which is a combined sum of activities of ^{226}Ra, ^{232}Th and ^{40}K, based on the estimation that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4180 Bq/kg of ^{40}K give the same dose rate .The radium equivalent was calculated using Equation (2).

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

where A_{Ra}, A_{Th} and A_K were activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively [10]

The external radiation exposure due to 226Ra, ^{232}Th and ^{40}K (H_{ex}) was calculated by Equation (3).

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

where A_{Ra}, A_{Th} and A_K were values of activities of ^{226}Ra, ^{232}Th and ^{40}K respectively.

The values should be less than unity for safety [11]. The internal hazard index due to exposure to radon and its short-lived products are also hazardous to the respiratory organs. The internal exposure to radon and its progeny products is quantified by the internal hazard index (H_{in}), which is determined by equation (4) and it should be less than unity.

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

The representative level index (I_γ) used to assess the levels of how much they were exposed to level of gamma radiation hazards related radionuclides were obtained using equation (5).

$$I\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (5)$$

where A_{Ra}, ATh and A_K were activities of (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K respectively.

The absorbed dose rate (D) in nGy/h in air at 1 m above of floor because of natural radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K was calculated using Equation (6).

$$D = 0.427A_{Ra} + 0.662A_{Th} + 0.427A_K \quad (6)$$

where A_{Ra}, A_{Th} and A_K were activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in Bq/kg respectively [12].
The annual effective dose rate which is the value of dose taken into human body was obtained by equation (7) to show the health effect of the absorbed dose rates.

$$AED(mSv/y) = D \times DCF \times IOF \times T \quad (7)$$

Where D is dosage in air, DCF is dose conversion factor of (0.7Sv/Gy), IOF is indoor occupancy factor (0.8) and T is the annual exposure time (8760h/y).

The excess lifetime cancer risk (ELCR) indicates the rate at which one can get cancer when they are exposed at a certain level and it was calculated using Equation (8).

$$ELCR = AEDE \times LS \times RF \quad (8)$$

where LS life we live of (70 years) and RF is the risk factor (Sv−1) of 0.05 for the community as stochastic effects [13].

3. RESULTS AND DISCUSSION

3.1 Specific Activities

The specific activity concentrations of various samples based on of country of origin (A-India, B-China and C-Uganda) are shown in Table 1 and Figure 1.

TABLE 1: Activity concentrations for the 12 samples based on country of origin.

Sample Code	Country	^{226}Ra Bq/Kg	^{232}Th Bq/Kg	^{40}K Bq/Kg
	A			
C1		18±0.92	52.5±2.62	292±14.61
C2		22±1.1	49.6±2.48	206±10.31
C3		11±0.57	49.6±2.48	275±13.75
C4		20±1.04	87.6±4.38	348±17.43
Average		**17.75±0.91**	**59.83±2.99**	**280.25±14.03**
	B			
C13		18±0.92	70±3.5	450±22.51
C14		16±0.81	58.4±2.92	479±23.99
C15		12±0.63	78.8±3.94	222±11.1
C16		13±0.69	84.6±4.23	386±19.3
Average		**14.75±0.76**	**72.95±3.65**	**384.25±19.23**
	C			
C17		25±1.27	178.1±8.9	891±44.55
C18		16±0.81	119.7±8.9	104±5.23
C19		18±0.92	207.3±10.3	805±40.25
C20		45±2.25	40.8±2.04	411±20.55
Average		**26±1.31**	**136±6.81**	**552±27.65**

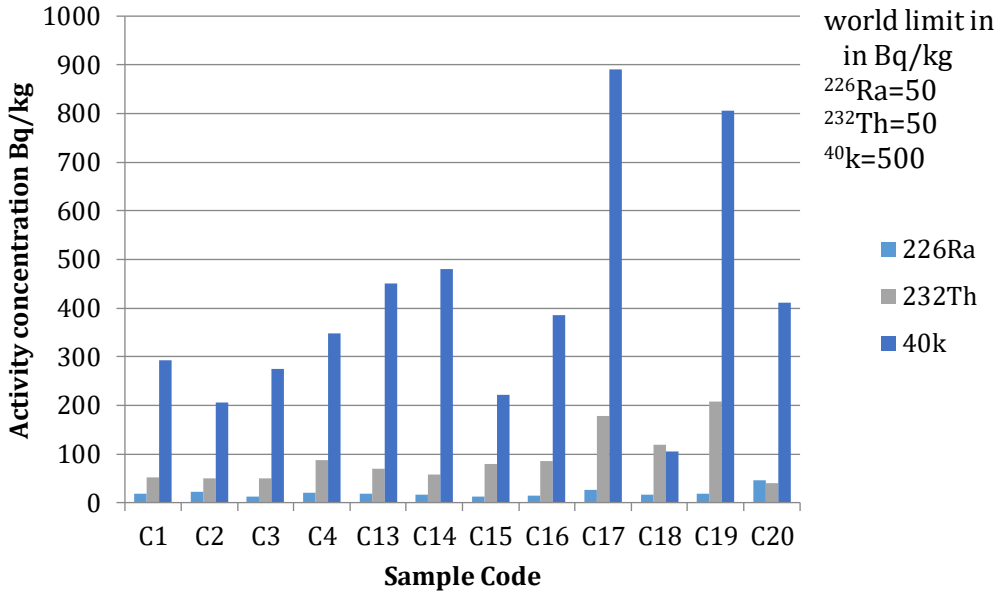

FIGURE 1: Activity concentration-based countries of origin (A, B and C).

The world respective average values are 50, 50 and 500Bq/kg [14]. As shown in Table 2, the concentration of ^{226}Ra is below the world average in all the samples from all the 3 countries. The activity concentration of ^{40}K is below the world average in countries A and B but above the world averages for those from country C. The concentration of ^{232}Th is higher than the world average in all the samples from all the studied countries.

TABLE 2: Average activity concentration based on country of origin compared with world average value.

Sample type	Sample number	^{226}Ra (Bq/Kg)	^{232}Th (Bq/Kg)	^{40}K (Bq/Kg)
A	(C1-C4)	17.75±0.91	59.83±2.99	280.3±14.03
B	(C13- C16)	14.75±0.76	72.95±3.65	384.3±19.23
C	(C17-C20)	26±1.31	136±6.81	552±27.65
World average ($Bqkg^{-1}$)		50	50	500

3.2 Radium equivalent activity (Ra_{eq})

Radium equivalent activity in all the samples is as shown in Fig. 2. All the samples had lower average values than the world acceptable limit of 370Bq/kg [15]. From the findings, the sanitary wares can be safely used as building and sanitation elements without creating any radiological risk.

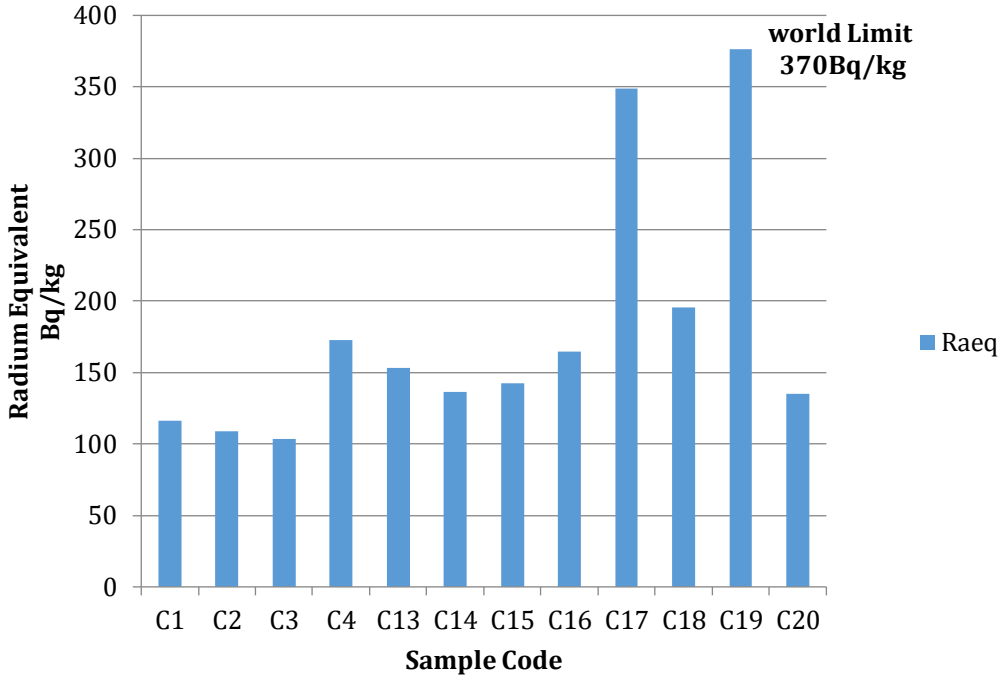

FIGURE 2: Radium Equivalent Activity in Bq/kg for sanitary ware sample based on country of origin.

3.3 Hazard indices

The Hazard indices for all the studied samples are shown in Table 3 and Figure 3.

TABLE 3: The radiological hazards for sanitary ware products based on import Countries.

CODE	ELCR ×10^{-3}	ADR	I_y	Ra_{eq} (Bq/kg)	H_{in}	H_{ex}	AED in mSv/y	AED_{out} mSv/y
C1	0.683	53±2.65	0.8±0.04	116±5.8	0.3±0.01	0.3±0.01	0.1±0	0.1±0
C2	0.633	49±2.45	0.7±0.03	108±5.44	0.2±0.01	0.3±0.01	0.1±0	0.1±0
C3	0.614	47±2.38	0.7±0.03	103±5.18	0.2±0.01	0.3±0.01	0.1±0	0.1±0
C4	1.009	78±3.91	1.2±0.06	172±8.64	0.4±0.02	0.3±0.01	0.2±0	0.1±0
AV	**0.735**	**56.±2.9**	**0.8±0.04**	**123.3±6.3**	**0.28±0.01**	**0.35±0.013**	**0.13±0.003**	**0.13±0.003**
C13	0.912	70±3.54	1.1±0.05	153±7.66	0.4±0.02	0.4±0.02	0.2±0.01	0.1±0
C14	0.823	63±3.19	1±0.05	136±6.82	0.3±0.01	0.4±0.02	0.2±0.01	0.1±0
C15	0.825	64±3.2	1±0.05	142±7.12	0.3±0.01	0.4±0.02	0.2±0.01	0.1±0
C16	0.969	75±3.76	1.1±0.05	164±8.22	0.4±0.02	0.4±0.02	0.2±0.01	0.1±0
AV	**0.882**	**68±3.42**	**1.05±0.1**	**148.8±7.5**	**0. 35±0.013**	**0.4±0.02**	**0.2±0.01**	**0.1±0**
C17	2.060	160±8	2.5±0.12	348±31.74	0.9±0.04	1±0.05	0.5±0.02	0.3±0.01
C18	1.106	85±4.29	1.3±0.06	195±9.76	0.5±0.02	0.5±0.02	0.3±0.01	0.2±0.01
C19	2.21	171±8.57	2.7±0.13	376±18.83	1±0.05	1±0.05	0.6±0.03	0.4±0.02
C20	0.804	62±3.11	0.9±0.04	135±6.76	0.3±0.01	0.4±0.02	0.2±0.01	0.1±0
AV	**1.545**	**120±5.6**	**1.85±0.1**	**263.5±0.7**	**0.68±0.03**	**0.725±0.04**	**0.4±0.018**	**0.25±0.01**

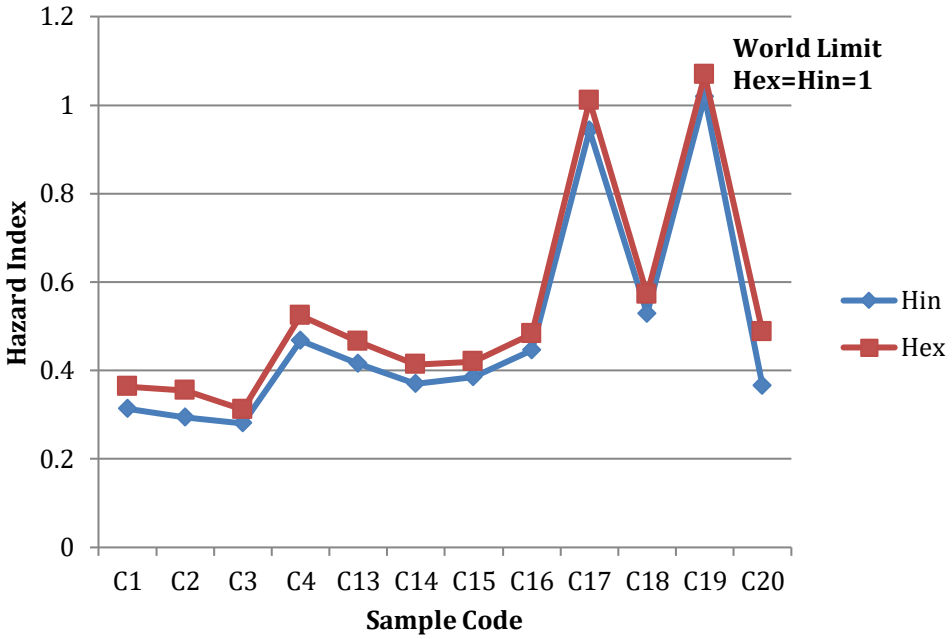

FIGURE 3: External and internal hazard for sanitary ware products based on importation country.

As shown in Table 4, the internal and external hazard indices apart from those from country C were less than world average value of unity hence they can be safely used in construction without any radiological risk.

TABLE 4: A comparison of the mean values for three countries of origin and world average with acceptable limits.

TYPE	ELCR $\times 10^{-3}$	ADR (nG/h)	Iy	Raeq (Bq/Kg)	Hin	Hex	AED in (mSv/y)	AED_O (mSv/y)
A	0.735	56±2.9	0.8±0.04	123.3±6.3	0.28±0.01	0.35±0.01	0.13±0.03	0.13±0.1
B	0.882	68±3.42	1.1±0.05	148.8±7.5	0.35±0.01	0.4±0.02	0.2±0.01	0.1±0.01
C	1.545	120±5.6	1.9±0.09	263.5±0.7	0.68±0.3	0.73±0.04	0.4±0.0.02	0.25±0.1
World average	**2.9×10^{-4}**	**84**	**6**	**370**	**1**	**1**	**1**	**1**

3.4 Absorbed Dose Rate (ADR)

The absorbed dose rate (ADR) is shown if Fig. 4. The average values were lower than the average indoor gamma dose rate of (84nG/y) [15]. This implies that sanitary ware products from all the countries can be safely used for sanitation purposes without creating any radiological risk to the public exposed.

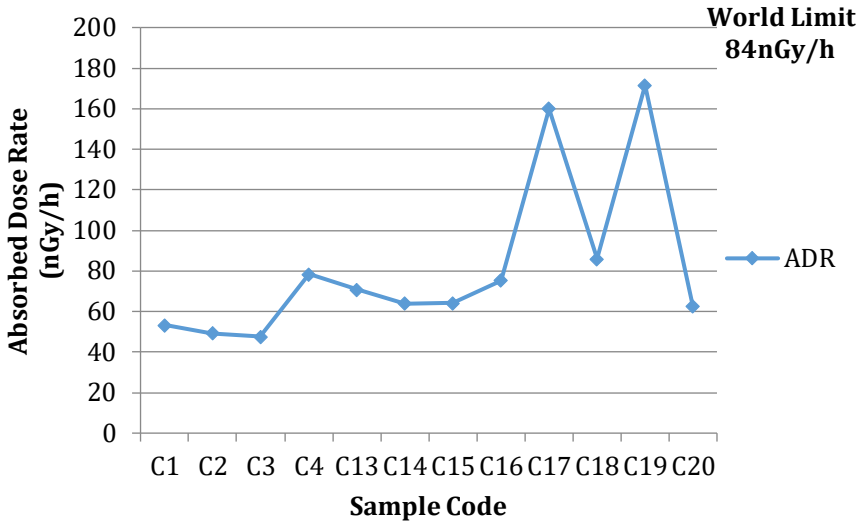

FIGURE 4: Absorbed dose rate in (nGy/h) for sanitary ware products based on country of origin.

3.5 Representative gamma index

The values of the representative gamma index are shown in Fig. 5. All the values are below the acceptable limit of 6 [4]. This implies that sanitary wares from all the countries used as building materials can be safely used without creating any radiological threat to the public.

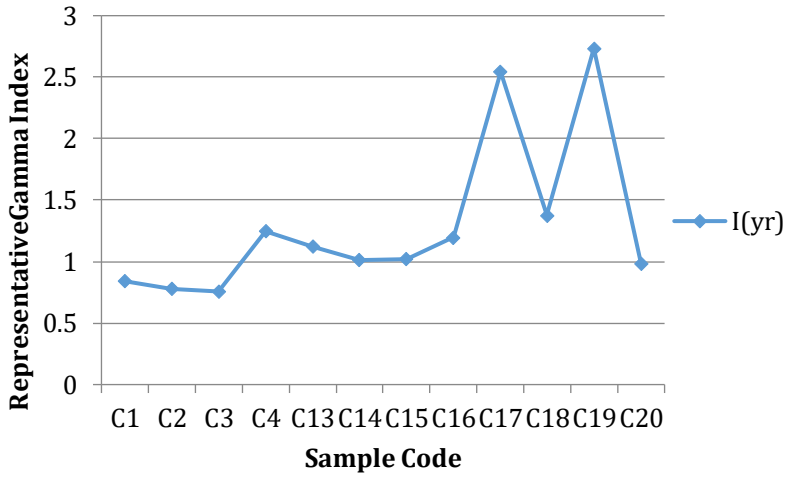

FIGURE 5: The representative gamma index for sanitary wares based on importation country.

3.5 Annual Effective Dose Rate (AEDR)

The obtained values of annual effective dose rate for indoor are shown in Fig. 6. Both the outdoor and indoor values were less than the world average limit of 1mSv/y limit set by European commission [16]. The calculated annual effective dose values showed that sanitary ware products from all the countries can be used for building and sanitation without any radiological risk to the population exposed.

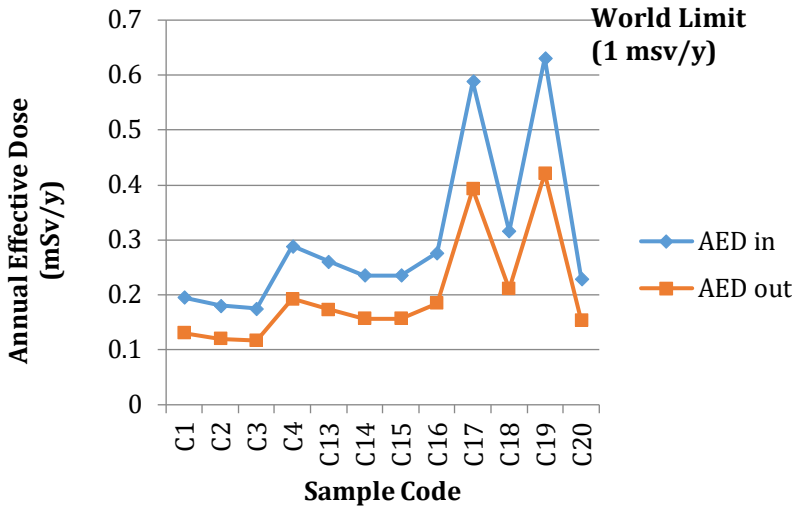

FIGURE 6: Annual effective dose for indoor and outdoor in mSv/y for the studied countries.

3.6 Excess Lifetime Cancer Risk

The excess lifetime cancer risk values ranged from a maximum of 2.060 $\times 10^{-3}$ to a minimum of 0.614 $\times 10^{-3}$ with an average value of 1.05 $\times 10^{-3}$. The values were higher than the world average value of 2.9×10^{-4} [15] hence the sanitary ware could be safely used for hygiene.

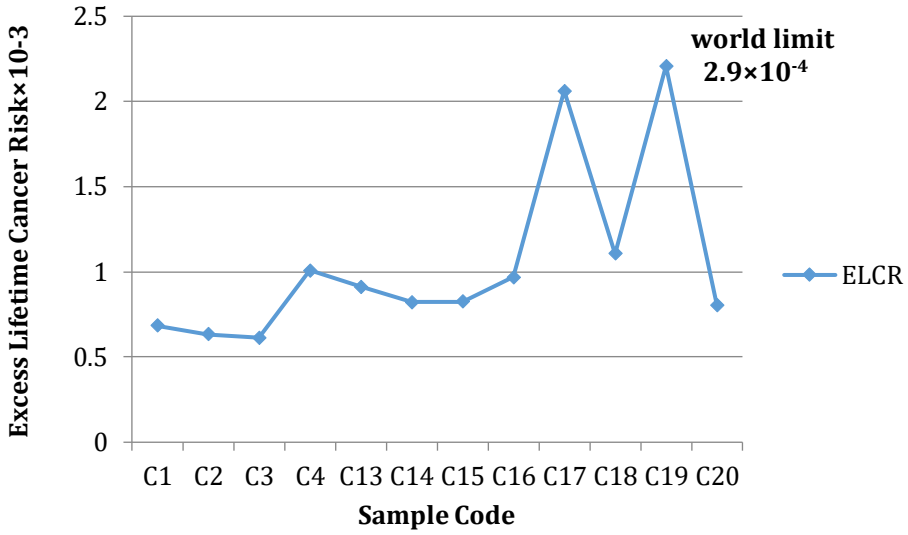

FIGURE 7: Excess Lifetime Cancer Risk Based on country of origin.

CONCLUSION

The natural radioactivity levels in ^{226}Ra, ^{232}Th and ^{40}K and related radiological hazards in samples from 3 countries were determined using a sodium iodide detector. A total of 12 samples were examined. Based on the findings, ^{226}Ra levels were below the world accepted averages in all the samples from the 3 countries. ^{232}Th levels were above the acceptable

world averages in all the samples from the 3 countries. ^{40}K levels were below the acceptable world averages for the samples from countries A and B but were higher for the samples from country C. The related radiological hazards were below the acceptable world levels.

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