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Danger Indicators of Natural Radionuclides in Consumed Products in the City of Hilla Markets

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Abstract

Many products contain several natural radionuclides in their composition. Frequent use of these products increases the cumulative radiation risk. This study aimed to measure the radioactivity using NaI (Tl)detector of consumer products found in local markets that contain natural radioactive materials (NORMs) and are used for various purposes. Average specific activity values are 3.52 Bq/kg for Uranium-238, 15.77 Bq/kg for Thorium-232, and 153.53 Bq/kg for Potassium-40. The radium equivalent (Raeq) was determined to be 45.22, and the average internal and external absorbed doses for the study samples were 39.77 and 21.21 nGy/h, respectively. The average values of the measured external and internal risk indexes are 0.12 and 0.13, and the representative level index is about 0.33. The study results were compared to global averages, according to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the International Commission on Radiological Protection (ICRP); the study determined that the levels of proven health risks in consumer products are safe and unlikely to pose a significant threat to the public.

Keywords: consumer products, radionuclides, NORMs, ICRP, UNSCEAR.

مؤشرات خطر النويدات المشعة الطبيعية في المنتجات المستهلكة في أسواق مدينة الحلة

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الخلاصة

تحتوي العديد من العناصر على عدد صغير من النويدات المشعة. الاستخدام المتكرر لهذه المنتجات يزيد من خطر الإشعاع التراكمي. هدفت هذه الدراسة إلى قياس النشاط الإشعاعي باستخدام NaI (Tl) للمنتجات الاستهلاكية الموجودة في الأسواق المحلية والتي تحتوي على مواد مشعة طبيعية (NORMs) وتستخدم لأغراض مختلفة. متوسط قيم النشاط النوعي هو 3.52 بيكريل/كغم لليورانيوم-238، و15.77 بيكريل/كغم للثوريوم-232، و153.53 بيكريل/كغم للبوتاسيوم-40. تم تحديد مكافئ الراديوم (Raeq) بـ 45.22، وكان متوسط الجرعات الممتصة الداخلية والخارجية لعينات الدراسة 39.77 و21.21 نانوكراي/ساعة على التوالي. ويبلغ متوسط قيم مؤشرات المخاطر الخارجية والداخلية المقاسة 0.12 و0.13، ويبلغ مؤشر مخاطر كاما حوالي 0.33. وبمقارنة نتائج الدراسة بالمعدلات العالمية الصادرة عن لجنة الأمم المتحدة العلمية المعنية بآثار الإشعاع الذري (UNSCEAR) واللجنة الدولية للوقاية من الإشعاع (ICRP)،

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خلصت الدراسة إلى أن مستويات المخاطر الصحية التي تظهر في المنتجات الاستهلاكية آمنة ومن غير المرجح أن تشكل تهديدا كبيرا للمستهلك.

1. Introduction

The human body contains minute quantities of many naturally occurring radioactive substances. The primary sources of these substances are derived predominantly from naturally occurring radioactive isotopes found in the food we consume and the air we inhale[1]. Approximately 11% of the radiation dose humans receive is attributed to the naturally occurring radioactive elements within the body. Radioactive isotopes, such as potassium-40 and carbon-14, can be found in the environment, including the air, water, and soil. These isotopes can enter our food and build up in our body tissues [2]. When estimating the dose that may be ingested by consuming radioactive materials through food, it is critical to consider all food types Specific weights of study samples that include relevant categories were used because measuring each sample directly from the research models is impractical. For a comprehensive understanding of the respective contributions of different food items, it is advisable to consult specific information available in the Food and Agriculture Organization (FAO) Food Balance Sheets (FBSs) or local nutritional statistics. Ideally, the quantification of radioactive substance levels in food should be conducted near the intake point [3].

Manufactured materials may contain natural radionuclides, which, upon decay, emit ionising radiation. These materials may commercially be distributed to the general public without supervision from the relevant regulatory body [4, 5]. These products may contain by-products or a primary source of radiation. Regular human use of these products increases the radiation exposure to the individual. Several guidelines have been established regarding using these commodities as a product for the general public. Oversight of competent authorities is strengthened by facilitating regulatory procedures related to exemption, how safety and improvement criteria are met, and how their use is approved[6, 7].

Radiation exposure is either external or internal. The spatial relationship between the radiation source and the human body largely determines how it is exposed to radiation[8, 9]. External exposure describes a person's exposure to radiation from sources outside the body. People can be exposed to radiation from external sources when they come into contact with products or materials containing radioactive substances or when they are directly exposed to gamma radiation. Conversely, internal exposure happens when the radiation source is inside the human body[10, 11]. This exposure typically occurs when breathing in radioactive particle-contaminated air or consuming food, water, or other products contaminated by radioactivity. The International Commission on Radiological Protection (ICRP) provides dose coefficients for the radionuclide of interest and other relevant parameters. Analytical methods often use these to estimate both internal and external exposure doses[12]. This simplifies the assessment of all possible health risks associated with radiation exposure.

This research focuses on calculating the concentration levels of natural radioactivity resulting from the repeated use of consumer products and the resulting cumulative effect that may affect human health in the long term. It also stresses the importance of strict adherence to radiation protection guidelines to mitigate the risks of radionuclides, their transmission to consumers, and the resulting contamination. This study aims to increase environmental awareness among residents of the study area and the critical role of environmental balance in the sustainability of the ecosystem including human and non-human entities.

2. Materials and Methods

2. 1. *Hypothetical Usage Scenarios*

Naturally occurring radioactive materials (NORMs) do not exist only in rocks and soil but also in substances that people use daily. Following the product classifications offered by the European Union, this study investigated the potential applications of NORMs across various product categories[10]. A comprehensive evaluation was conducted for each product category, considering several factors. These factors included the specific application area on the human body, the average duration of product usage under normal and extreme conditions, the probable routes through which radiation exposure may occur, and the average duration of consumption for each products category throughout the specified period. An additional hour and a half will be allocated to cases of excessive use of the product as a statistical measure, which is indicated in Table 1[9]. The typical usage is calculated primarily based on studies and research related to this information. However, it is essential to realize that the actual duration of use may vary due to each user's unique behaviors and circumstances.

Table 1: A brief overview of the potential mechanism of use and exposure pathways for natural radionuclides in Consumed Products in the City of Hilla Markets

Categories of Goods	Location of Use	Average Usage Time (min)		Excessive usage assumptions	Exposure Routes
		Normal Use[14]	Overused		
Slimming Belts	Waist, abdomen, etc.	301	391	overused	External and inhalation
Slippers	Foot wares	301	391	overused	External
Cosmetics	Face and body	487	577	Accidental Ingestion	Inhalation and ingestion
Necklace	Neck, Hand	487	577	overused	Inhalation
Clothing	Depending on usage	1440	1530	overused	Inhalation
Mattress	Whole body	470	560	Sickness/ oversleeping	Inhalation

2. 2. The Samples' Preparation

As can be seen in Table 2, 18 samples of imported goods and consumables available on the local markets were gathered. Each sample was then placed in a plastic bag with the name of the substance or product that people use, the country of origin, and whether imported or locally manufactured, written on it. All samples were cleaned of contaminants and rinsed with distilled water. The studied products were kept in a moisture-free oven for 48 hours at 60 °C to produce a constant weight and stop moisture absorption before radioactivity measurement. The samples were then electronically ground in an electric mill to verify homogeneity. Samples were weighed using a sensitive digital balance. They were left for a month to ensure a radiant secular balance before analysing the samples using the NaI (Tl) detector.

Table 2: Consumer Product Samples and Codes.

Number	Product Categories	Code of Samples
1	Health Supplements	H_1, H_2 and H_3
2	Slippers	S_1, S_2 and S_3
3	Cosmetics	C_1, C_2 and C_3
4	Necklace	N_1, N_2 and N_3
5	Clothing	L_1, L_2 and L_3
6	Mattress	M_1, M_2 and M_3

2. 3. Setting for Experiment

In the experimental setup for this work, a NaI (Tl) scintillator detector 3 inches by 3 inches in size was utilized. This detector is a gamma-ray collection equipment extensively utilized due to its consistent energy resolution and robust light output. An analog-to-digital converter (ADC) was used to transform the detector's optical signals into digital data. These digital data were then analyzed by a multichannel analyzer (MCA) made by (Alpha Spectra, Inc.-12I12/3), known as the DigiBase analyzer. In order to guarantee a seamless workflow, the spectrophotometry and data processing procedures were carried out with the assistance of the MAESTRO-32 software[14]. The detector crystal takes in the photon and transforms its energy into a single electron (photoelectron). After that, the photoelectron is subjected to multiplexing through dynamic diodes arranged in a chain inside a photomultiplier tube (PMT) to get a pure signal. Each dynode boosts the signal by releasing several electrons for every incoming electron. The enhanced signal is gathered and transformed into an electrical one. A series resistor at the base of the (PMT) controlled the voltage and the characteristics of the amplified signal that was finally produced[15]–[17]. The experiment starts by calibrating the detector to guarantee precise readings of the energy to be measured before starting the measurements. Moreover, we must ascertain the effectiveness of absorbing various gamma-ray energies; this process is known as determining efficiency. To do this, intricate changes are typically required to account for the different levels of efficiency that exist throughout the energy spectrum. The removal of certain background factors comes next. Evaluating background radiation is a prerequisite for obtaining precise activity measurements from a sample. This particularly applies to consumer items.

3. Theoretical Computations

The International Commission on Radiological Protection (ICRP) provides dose coefficients, which are tools used to calculate the potential harm caused by inhaling or swallowing specific radioactive materials, known as equivalent dose and effective dose. However, choosing the correct dose coefficient for analyzing bioassay data (measurements from within someone's body) is more complex. It depends on several factors, such as the type of radioactive material, how it entered the body (breathing or swallowing), its physical form (e.g., particle size), and how long it has been there[18].

3. 1. Specific Activity (A)

Specific activity is the radioactivity of a particular nuclide per unit mass; its unit is Bq kg^{-1} or Ci g^{-1}. The specific activity of a given model becomes extremely important in radioactivity analysis [19]. Specific activity(A) of a particular radioactive sample is calculated using the following relation:

$$\text{Specific Activity(A) (Bq/Kg)} = \frac{N_{net}}{t \times \varepsilon \times I_{\gamma} \times m} \quad (1)$$

Where: N_{net} is the area under the photopeak of the spectrum, representing the number of detected gamma rays from the desired isotope, t is the counting time in seconds, the duration for which the detector collects data, I_γ is the probability of a specific radionuclide emitting gamma ray of specific energy, m is the sample weight in kilograms, the amount of material being analysed, and ε is the detector efficiency at the specific gamma energy, this is how effectively the detector captures and registers the chosen gamma rays.

Measuring a sample's specific activity tells us how radioactive it is, helping us assess potential radiation hazards. This is crucial for safety in various fields, from industry to healthcare. Designing safe and effective radiopharmaceuticals in nuclear medicine relies heavily on specific activities. It lets doctors give patients the right amount of radiation for therapy or diagnosis, minimizing risks. This measurement also ensures compliance with regulations. Different radioactive materials have different safe limits set by various agencies depending on factors like application and risk [9, 20].

3. 2. The radium-equivalent activity (Ra_{eq})

Radium-equivalent activity is the primary factor for assessing the radiation risk of a radioactive material containing radionuclides. This provides information on the amounts of three primary radioactive elements (Thorium-232, Radium-226, and Potassium-40) present, measured in units of (Bq/kg). Ra_{eq} integrates risk scores for all three components, comprehensively assessing the primary radiation risks associated with the entire material [21, 22]. The mathematical equation that guides the calculation of Ra_{eq} is explained in detail as follows:

$$Ra_{eq}=1\cdot 0A_U+1.430A_{Th}+0.0770A_K \tag{2}$$

Where: A_U is the specific activity of uranium-238, A_{Th} is the specific activity of thorium-232, and A_K is the specific activity of potassium-40.

Ra_{eq} takes into account not only the radiation present immediately but also the risks that accompany the use of these materials throughout their life. This number combines the radioactivity of three radioactive isotopes - Radium-226, Potassium-40, and Thorium-232 - into one easy-to-understand number. Calculating each element's concentration and risk ratings provides a single, comprehensive measure of the radiation risks associated with a substance.

3. 3. Evaluation of External and Internal Doses

The external Exposure dose is from direct radiation or from sources or objects containing radioactive materials. External dose assessments should consider the time of exposure, distance of the source, source activity, potential shielding and isotope. Depending on age, the total external dose caused by NORMs added to consumer products also differs. While ^{238}U and ^{232}Th are alpha emission sources, excluding ^{40}K, they being 89% beta emitters and only 11% gamma emitters are the reason for the low external dose from NORM. The following equationis used to calculate the external exposure dose rate (D_{ext}) [21]:

$$D_{ext}.(Sv/y) = C_R \times E_T \times DCF_{external} \tag{3}$$

Where: C_R is the activity concentration of the NORM in the product (Bq/kg), E_T is the exposure time per year (h/y), and $DCF_{external}$ is the external dose conversion factor Sv/h per Bq/g.

The internal dosage is the amount of radiation the body receives due to the uptake of radioactive matter through several routes (inhalation or ingestion). After it enters the body, it tends to concentrate in specific glands or tissues and then deliver a radiation dose to various glands or tissues. While external doses originate from gamma radiation doses, internal doses mainly result from inadvertent inhalation and ingestion of NORMs during normal and abusive usage of consumer products containing them. It can be worked out with relevant analytical parameters. The contribution from the inhalation is mostly due to radioactive aerosols that consist of radon and thoron gases that are inhaled and deposited in the respiratory tract system. The following formula provides the computation for figuring out the internal radiation dose rate ($D_{int(inh)}$)[21]:

$$D_{int(inh)}(mSv/y) = C_R \times I_R \times H_t \times DCF_{inh} \tag{4}$$

Where: C_R is the activity concentration of the NORM in the product (Bq/kg), I_R is the inhalation rate (g/h), H_t is the annual exposure time (h/y), and DCF_{inh} is the inhalation dose conversion factor (mSv/Bq).

3. 4. The Representative Level Index (I_γ)

One of the most significant statistics to consider when assessing the possible dangers posed by gamma radiation caused by natural gamma emissions present in materials is the representative level index, also known as gamma level index I_γ. The level of radiation danger linked with these radioactive elements can be evaluated using this index[22] according to the equation:

$$I_\gamma = \frac{A_U}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \tag{5}$$

3. 5. Radiation Hazard Indices Calculation

When evaluating radiation-related risks, it is necessary to consider two important indicators: the external (H_{ex}) and the internal (H_{in}) hazard indices. These indicators are essential to measure the biological risks that arise from exposure to natural gamma rays and to understand the potential health risks associated with ionizing radiation. (H_{ex}) specifies the external exposure to the radionuclides, while (H_{in}) indicates the internal exposure due to radon and thoron gases resulting from the decomposition of ^{238}U and ^{232}Th, harmful to the respiratory organs. The methodology for calculating these indicators was described by Abu Hanifah et al. [7] and according to the equations shown below:

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{6}$$

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \tag{7}$$

4. Results and discussion

4. 1. Specific Activity and Ra_{eq}

The results of the specific activity and the radium-equivalent activity of the studied samples are shown in Table 3 and Figs 1 and 2 for ^{238}U, ^{232}Th and ^{40}K of the 18 samples of the consumer products collected from the local markets in the city of Hilla. The specific activity of ^{238}U, ^{232}Th, and ^{40}K in these products ranged from 1.59±0.913 Bq/kg to 30.4±0.203 Bq/kg, with an average value of 3.52±0.145 Bq/kg, from 5.74±0.064 Bq/kg to 31.75±0.005 Bq/kg with an average value of 15.77±0.149 Bq/kg and from 20.989±0.21 Bq/kg to 369.52±1.406 Bq/kg with an average value of 153.53±0.895 Bq/kg, respectively. The Ra_{eq} values ranged between 15.36±3.030 and 99.70±12.08 Bq/kg with an average value of 45.22±7.08 Bq/kg. The necklace samples had the highest activity concentrations of ^{238}U (30.4±0.203 Bq/Kg) and ^{40}K (369.52±1.406 Bq/Kg) in N_2 and ^{232}Th (31.75±0.005 Bq/Kg) in N_1. The values of these doses are less than the permissible limit recommended by the International Committee for Radiation Protection. The close distance from the body's respiratory system when using the products and the mechanism of exposure to nuclide activity make the process of introducing nuclides into the human body as a result of gaseous decomposition of U-238 and Th-232 possible and simple[23, 24].

Table 3 ^{232}Th, ^{238}U and ^{40}K Activity concentration ($Bq{\cdot}kg^{-1}$) in consumer products.

Number	Specimen Code	Specific Activity [Bq/kg] K-40	U-238	Th-232	(Ra_{eq}) [Bq/kg]
1	H_1	143.9±0.824	1.59±0.913	21.06±0.011	24.78±8.045
2	H_2	136.33±0.890	7.54±0.231	8.23±0.013	29.85±9.07
3	H_3	111.08±0.703	3.08±0.145	11.59±0.072	28.21±5.402
4	S_1	30.017±0.366	6.65±0.011	12.33±0.009	26.59±6.208
5	S_2	154.49±0.858	11.8±0.062	18.14±0.008	49.64±8.007
6	S_3	186.82±1.246	12.2±0.074	21.97±0.049	58.01±9.04
7	C_1	117.98±0.833	12.8±0.07	17.87±0.06	47.44±8.05
8	C_2	45.423±0.441	3.65±0.034	5.74±0.064	15.36±3.030
9	C_3	351.52±1.36	28.7±0.176	30.72±0.08	99.70±12.08
10	N_1	120.05±0.741	8.03±0.026	31.75±0.005	62.68±5.073
11	N_2	369.52±1.416	30.4±0.203	20.59±0.164	88.30±13.04
12	N_3	183.1±1.932	6.23±0.006	6.908±0.007	30.21±5.012
13	L_1	39.055±0.36	7.16±0.005	5.948±0.057	18.67±4.044
14	L_2	171.17±1.001	10.9±0.055	14.03±0.107	44.14±7.066
15	L_3	129.22±0.773	8.36±0.03	8.109±0.006	29.95±5.083
16	M_1	20.989±0.21	4.95±0.158	7.604±0.037	17.44±4.050
17	M_2	151.55±0.85	5.15±0.001	10.52±0.053	31.86±5.085
18	M_3	301.38±1.32	26.4±0.203	30.03±0.105	93.55±10.02
Max.		369.52±1.406	30.4±0.203	31.75±0.005	99.70±12.08
Min.		20.989±0.21	1.59±0.913	5.74±0.064	15.36±3.030
Average		153.53±0.895	3.52±0.145	15.77±0.149	45.22±7.08

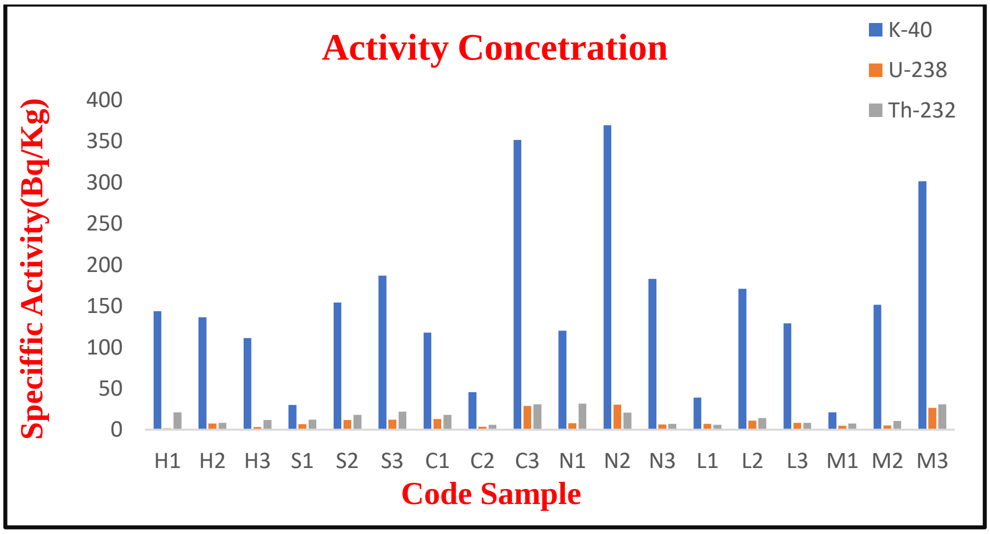

Figure 1: Specific activity of consumer product samples.

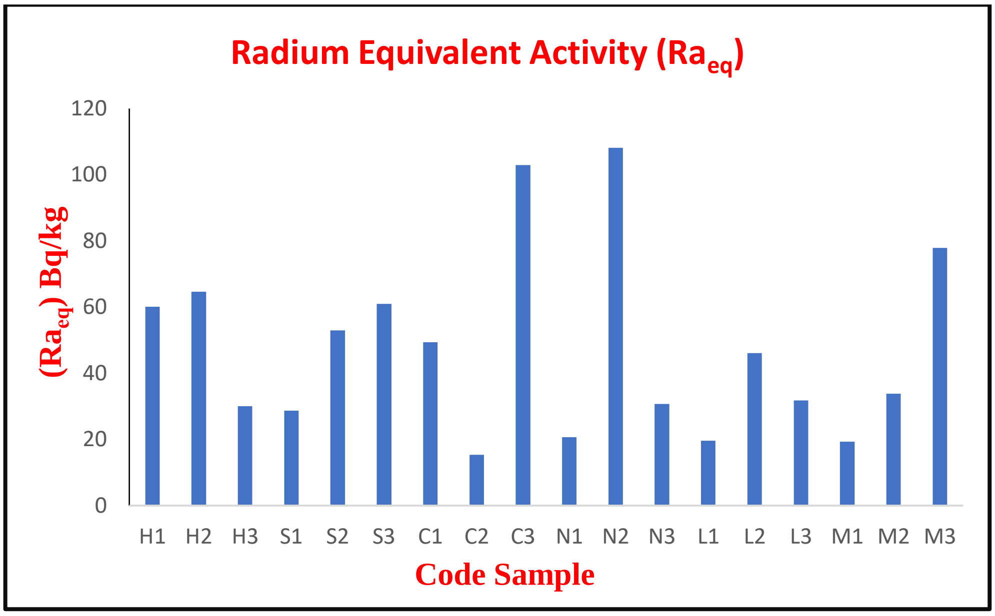

Figure 2: Radium equivalent activity concentration for radiological hazard assessment in consumer products.

4. 2. The Results of D_{out}, D_{in}, $H_{(ex)}$, $H_{(in)}$ and I_γ Parameters

Table 4 shows the results of the calculated doses of H_{ex}, H_{in}, and I_γ for the studied consumer product samples from the local markets of the city of Hilla. The average internal and external absorbed dose rates for the studied samples were 39.77 and 21.21 nGy/h, respectively. Noting that the global average absorbed dose rate from exposure to external gamma radiation (mSv/h) is approximately 59 mSv/h, according to the 2017 UNSCEAR report [24]. The obtained results do not indicate any carcinogenic effects or a significant risk to the public when using these products. According to the Radiation Protection Report, the average value is less than one for the measured and reported external danger index of 0.12. The internal and gamma hazard indices for the studied samples were calculated to be 0.13 and 0.33, respectively, which are less than one. These values, shown in Table 4, fall within the permissible limit of international values [24, 25]. The result of radionuclide radioactivity determination for the different commodities and all models and input data containing NORM indicated that the measured external dose results were lower than the internal dose because potassium (K-40) decays with 0.89 beta and 0.11 gamma. As for the internal dose rate, it was high due to radon and thoron gases resulting from the decomposition of ^{238}U and ^{232}Th, which are harmful when ingested[25].

Table 4: Danger indicators for radionuclides in consumer products in the markets of Hilla.

Number	Specimen Code	Hazard Index		(I_γ)	absorbed dose rate (nGy /h)	
		(H_{ex})	(H_{in})		D_{out}	D_{in}
1	H_1	0.12±0.03	0.12±0.03	0.32±0.07	19.81±4.7	36.28±8.6
2	H_2	0.08±0.03	0.1±0.04	0.22±0.08	14.28±5.2	**27**.03±9.6
3	H_3	0.08±0.02	0.08±0.02	0.21±0.05	13.25±3.4	24.58±6.2
4	S_1	0.07±0.02	0.09±0.03	0.19±0.06	11.98±3.7	22.11±6.9
5	S_2	0.13±0.03	0.17±0.04	0.36±0.07	23.16±4.8	43.32±9.0
6	S_3	0.16±0.03	0.19±0.04	0.43±0.08	27.07±5.2	50.52±9.6
7	C_1	0.13±0.03	0.16±0.04	0.34±0.07	21.93±4.7	40.98±8.8
8	C_2	0.04±0.01	0.05±0.02	0.11±0.04	7.145±2.4	13.35±4.5
9	C_3	0.27±0.04	0.35±0.05	0.73±0.10	46.99±6.7	88.66±13
10	N_1	0.17±0.02	0.19±0.03	0.45±0.05	28.43±3.5	52.03±6.6
11	N_2	0.24±0.03	0.32±0.04	0.65±0.09	42.24±5.6	80.54±10
12	N_3	0.08±0.02	0.10±0.03	0.23±0.05	14.80±3.2	28.16±6.1
13	L_1	0.05±0.02	0.07±0.02	0.13±0.05	8.63±2.9	16.29±5.5
14	L_2	0.12±0.03	0.15±0.04	0.33±0.07	20.89±4.4	39.32±8.2
15	L_3	0.08±0.02	0.10±0.03	0.22±0.06	14.29±3.6	27.08±6.7
16	M_1	0.05±0.02	0.06±0.02	0.12±0.05	7.884±2.9	14.62±5.4
17	M_2	0.09±0.02	0.10±0.03	0.24±0.06	15.23±3.6	28.58±6.6
18	M_3	0.25±0.04	0.32±0.06	0.68±0.11	43.85±6.9	82.50±13
Min.		0.04±0.01	0.05±0.02	0.11±0.04	7.145±2.4	13.35±4.5
Max.		0.27±0.04	0.35±0.05	0.73±0.10	46.99±6.7	88.66±13
Average		0.12±0.02	0.13±0.03	0.33±0.06	21.21±4.2	39.77±7.7

5. Conclusions

The radioactivity concentration calculated in this study attracted the most attention, namely samples C_3, N_2, and M_3, which consequently increased the annual effective dose rate for general public. The dose limits established by the International Commission on Radiological Protection (ICRP) are intended to function as a threshold to mitigate deterministic effects and minimize the likelihood of stochastic impacts. The dosimetric findings assessment of all consumer goods available in the markets in the city of Hilla generally indicated radiation levels below the maximum recommended dose. From these results, it was noted that the external dose was lower than the internal dose due to the decay properties of K-40, and the internal dose ratio was higher, mostly due to the presence of radon and thoron gases resulting from the decay of ^{238}U and ^{232}Th, which if ingested can be harmful.

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