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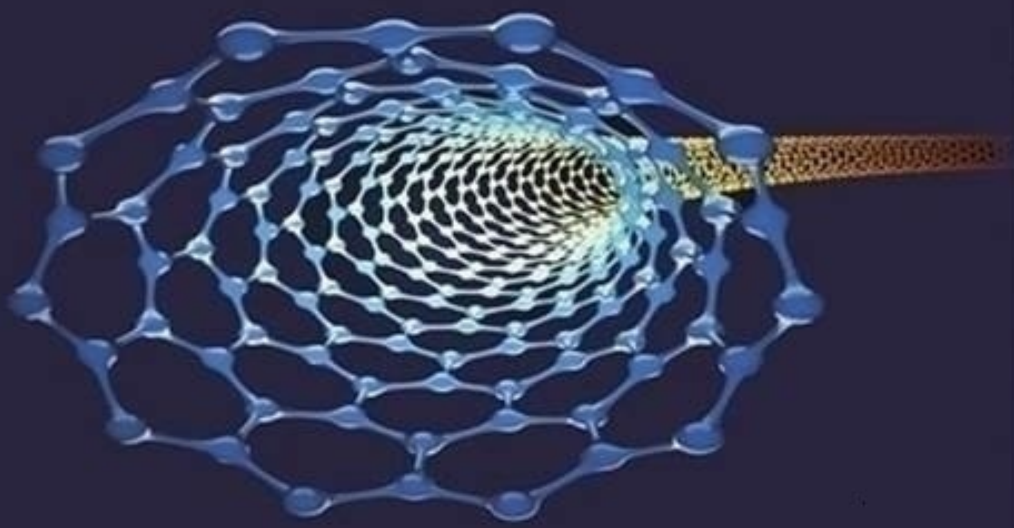

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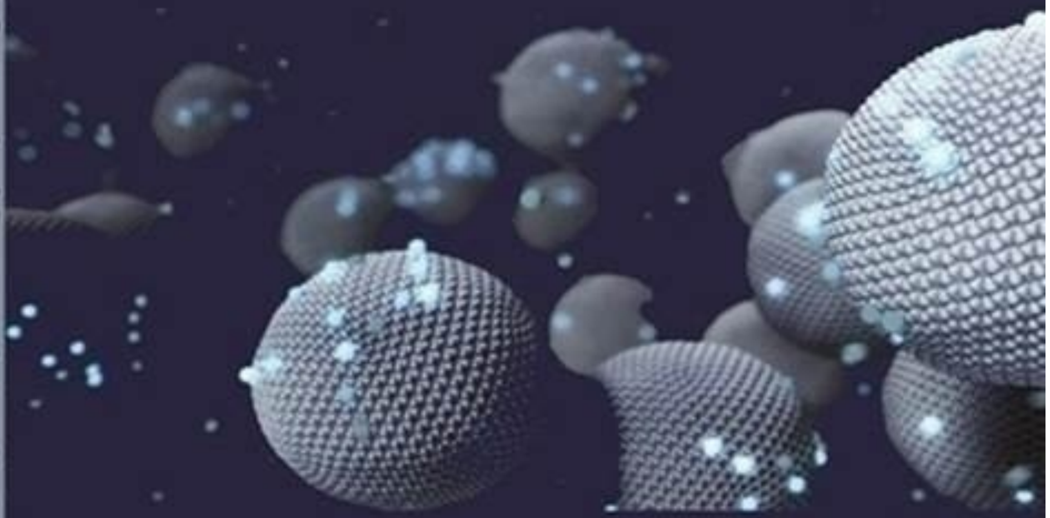

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RESEARCH PAPER

Assessment of natural radionuclides in cooking salts available in Kurdistan region-Iraq

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A B S T R A C T:

Eighteen local and imported salt samples were collected in markets of Kurdistan region. The cooking salt as an essential foodstuff element in meals of population in all over the world has been examined for radioactivity assessment. Gamma ray spectroscopy of NaI (Tl) was used to obtain the spectra and measuring the specific radionuclide activities of 226Ra, 232Th and 40K in salt samples. The related radiological indices of radium equivalent (Raeq), indoor absorbed dose, indoor annual effective dose equivalent (Ein), the internal index (Hin), annual committed effective dose (Eing) and excess life time cancer (ELCR) were calculated which were below the world safety recommendation values declared by UNSCEAR2000 and WHO. Statistics of Pearson correlation were applied to the obtained data to establish the correlation between primordial radionuclide's and radiological hazards.

KEY WORDS: RADIOACTIVITY, NAI(TL) DETECTOR, SALT, CANCER RISK, ANNUAL DOSE
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1. INTRODUCTION:

The environmental radioactive material can be divided into natural and man-made radionuclides. The former is caused by cosmic and terrestrial radiation, while the latter are a result of nuclear worldwide tests and accidents. Natural primordial radionuclides are exposed to humans and are present in the environment with varying abundances and non-identical distributions [1]. According to [2], there are four different ways that radioactive materials can enter the human body: inhalation from breathing radioactive aerosols or dust particles; ingestion from radioactivity being transferred to the mouth; absorption from entry through intact skin; and injection from an object puncturing the skin with radioactive materials. The nature, the geology, and the location of food production are just a few of the many variables that might affect the presence of radionuclides in food. The common radionuclides in food are the long lived ^{40}K, ^{232}Th and ^{238}U with their associated progeny. According to [3], the primary sources of the internal dose that is continuously exposed inside the human body as a result of eating are the single decay scheme of potassium-40 and the decay series of thorium-232 and uranium-238 with their daughters. Mines and the ocean floor both contain salt that can be extracted. Different industries use salt and the components it produces for human use [4]. The measurement of radioactivity in cooking salt has been examined by numerous researchers from around the world [5]; [6]; [7]; [8]; [4]; [9]; [10]; [11]. The purpose of the current work is to determine the level of natural primordial radionuclides and the associated radiological hazard index in local and imported cooking salt available in Kurdistan markets.

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2.Materials and method:

Sampling From Kurdistan's local markets, 18 samples of various cooking salts were gathered. For the salt samples, the drying and sieving processes were carried out, and 1 kg of each was placed inside a sealed Marinelli beaker and stored for at least 30 days in order to acquire the secular equilibrium between the parent and progeny radionuclides. Different kinds of local and imported cooking salts are displayed in Table 1.

Here we provide some basic advice for formatting your mathematics, but we do not attempt to define detailed styles or specifications for mathematical typesetting. You should use the standard styles, symbols, and conventions for the field/discipline you are writing about.

TABLE 1. Type and origin of the studied salt samples.

Name	Code	Production Country
Khosh	S1	Turkey
Almaeda	S2	Iraq
Alnima	S3	Turkey
Altabaq	S4	Iraq
Altunsa	S5	Turkey
Altunsara	S6	Iraq
Awagrd	S7	Iraq
Bilbak	S8	Turkey
Cihan	S9	Turkey
Dolfin see	S10	Turkey
Golha	S11	Iran
Hakan	S12	Turkey
Nawras	S13	Turkey
Raz	S14	Turkey
Sevan	S15	Turkey
Salt	S16	Iraq
Surdash	S17	Iraq
Zer	S18	Turkey

3. Gamma Ray Spectrometry Analysis

Gamma ray spectrometry of NaI (Tl) with the crystal size of 3″×3″ (SILENA type model 3S3), was used to determine the specific activity of primordial radionuclides in eighteen salt samples. The system consists of preamplifier, amplifier, multi-channel analyzer of 512 channels and a high voltage power supply (521681 LYBOLD) with the range and operating voltage of 0-1500 (800 Volt).

The detector resolution was 7.4KeV at 662KeV photo peak gamma line of ^{137}Cs. Two different materials of lead (10 cm) and copper (20mm) were used to reduce the background and attenuated the x-ray fluorescence respectively. A CASSY software program was used to acquire and identify the spectrum. The point source of ^{226}Ra and its descendants, ^{214}Pb (242, 295, and 352 KeV) and ^{214}Bi (609 and 1120 KeV), were used to calibrate the energy for NaI (Tl) gamma ray spectrometry, and the three famous activity sources of ^{137} Cs, ^{60}Co, and ^{152}Eu were used to calibrate the complete peak efficiency. The salt samples were counted within the calibrated spectrometer for 21600 sec. The obtained net salt spectra (after subtracting the background) have been analyzed using the indirect methods to measure the specific activities of ^{226}Ra and ^{232}Th. The activities of ^{40}K, ^{226}Ra and ^{232}Th with the unit of Bq/Kg was estimated from the photo peak energy of 1460 KeV, 352 (^{214}Pb) KeV and 911 (^{228}Ac) KeV, respectively. The following formula was used to determine the specific activity in salt samples[12].

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$$A_s = \frac{Ns}{\varepsilon_\gamma \, I_\gamma \, t \, m_c} (Bq \; Kg^{-1}) \quad (1)$$

4. Results and Discussion

4.1 Activity concentration

The specific activity for primordial radionuclide in the cooking salt samples have been reported in Table 2. and shown in Figures. 1 and 2.

TABLE 2. Specific activities of primordial radionuclides in salt samples.

Sample Code	**Specific Activity (Bq / Kg)**		
	^{226}**Ra**	^{232}**Th**	^{40}**K**
S1	0.304±0.023	ND	1.235±0.176
S2	0.256±0.021	1.556±0.102	8.774±0.47
S3	0.313±0.023	0.253±0.042	11.623±0.541
S4	0.366±0.025	ND	2.118±0.231
S5	0.413±0.027	0.387±0.052	13.173±0.576
S6	0.360±0.025	0.803±0.075	39.557±0.999
S7	0.339±0.024	0.408±0.054	11.093±0.529
S8	0.356±0.025	ND	3.555±0.299
S9	ND	0.641±0.067	4.815±0.348
S10	0.430±0.027	ND	13.236±0.578
S11	0.241±0.020	ND	2.067±0.228
S12	0.453±0.028	ND	17.182±0.658
S13	0.463±0.028	ND	17.371±0.662
S14	0.497±0.029	0.781±0.074	19.035±0.693
S15	0.523±0.030	0.472±0.058	27.178±0.828
S16	0.466±0.028	0.338±0.049	29.006±0.855
S17	0.359±0.025	ND	13.942±0.593
S18	0.432±0.027	0.394±0.053	9.719±0.495

*ND: Not Detection

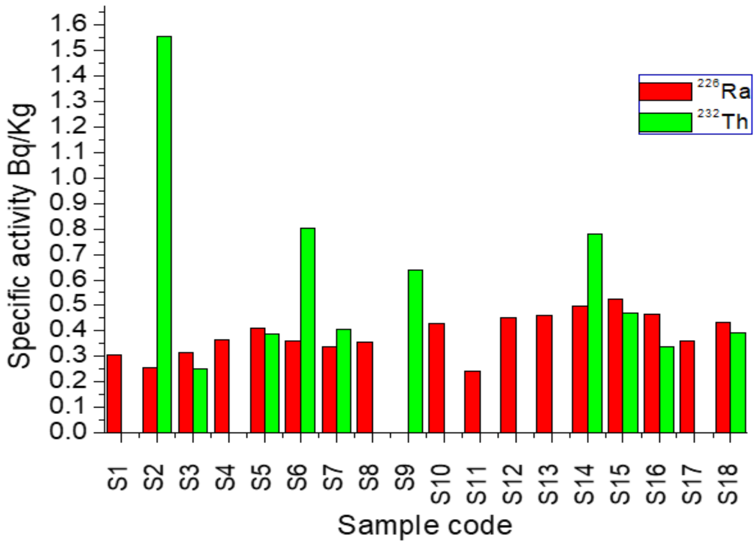

FIGURE 1. Specific activities of ^{226}Ra and ^{232}Th in salt samples.

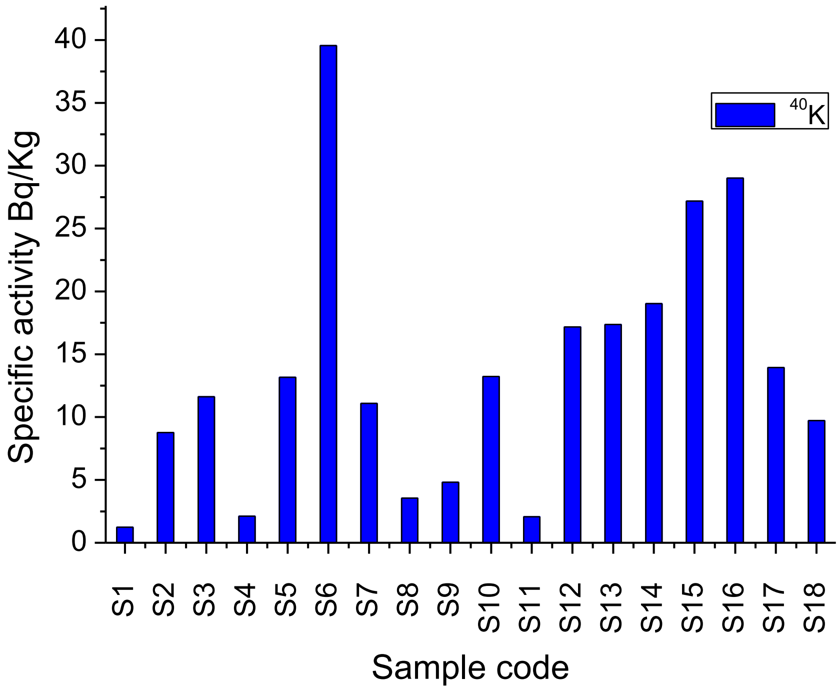

FIGURE 2. Specific activities of ^{40}K in salt samples.

Radium (^{226}Ra) was detected in all salt samples (except S9) and measured with a minimum of not detectable (ND) in S9, a maximum of 0.523±0.030 in S15 and the average specific activities was 0.387±0.026 Bq.kg^{-1}. Thorium (^{232}Th) was detected in salt samples with a minimum ND value, a maximum of 1.556±0.102 in S2, and the arithmetic mean of 0.693±0.063 Bq.kg^{-1}. Potassium (^{40}K) was detected in all salt samples with a minimum value of 1.235±0.176 in S1, a maximum of 39.556±0.999 in S6 with an average of 13.593±0.542 Bq.kg^{-1}.

The wider variation in the level of primordial radionuclides present in salt samples could be linked to the geological and geographical variation in mining or sea origin in which the salts are produced.

The recorded specific activity of ^{226}Ra has lower value in compare to both ^{232}Th and ^{40}K. Similarly the measured activity of ^{232}Th was lower than the value reported in Iraq [5]; [6]. The higher ^{40}K activity returned

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to the hyposodic iodized salt with low Na and a high content of KCl, K3C6H5O7, KI (potassium iodide) with the ratio of (31.3%) [4]. The obtained ^{40}K activity lied below the permitted world average of (400Bq. kg^{-1}). Table 3. Presents a comparison between the obtained salt activities with others published in different countries.

TABLE 3. Comparison of salt samples specific activities with those of other countries.

Country	Specific activity Bq/Kg			Reference
	^{226}Ra	^{232}Th	^{40}K	
Iraq	5.6±2.1	9.0±2.8	16.6±5.2	[5]
Iraq	0.508±0.359-19.577±2.230	4.790±0.670-9.674±0.953	64.216±4.216-239.981±8.150	[6]
Turkey	ND -3±0.4	4.1 ± 0.7- 7.3 ± 1.1	ND- 34.0 ± 5.3	[7]
Italy	-------	--------	2.61±0.12	[4]
Iraq	4.161-32.138	1.426-12.456	334.4-3864.1	[8]
Turkey	7.32±0.9	2.72±0.7	488.53±21.61	[9]
Pakistan	ND	ND	10 - 69	[13]
Egypt	0.46±0.02-32.6±1.6	0.2±0.01-10.5±0.5	0.42±0.02-158.6±7.8	[11]
Kurdistan-Iraq	ND-0.523±0.03	ND-1.556±0.102	1.235±0.176-39.556±0.999	Present study

4.2 Radium Equivalent

The effect of primordial radionuclide of ^{226}Ra, ^{232}Th and ^{40}K can be combined in a single physical quantity known as radium equivalent and obtained from the following equation [14].

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

The quantities $\boldsymbol{A_{Ra}}$, $\boldsymbol{A_{Th}}$ and $\boldsymbol{A_K}$ in eq.2 can be defined as specific activities of ^{226}Ra, ^{232}Th and ^{40}K in a unit of Bq.kg^{-1}, Ra_{eq} represents that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K generates the same external and internal gamma dose rate [14]. The obtained values are presented in Table 4, column 2. It was ranged from 0.339 to 4.554 with an algebraic mean value of 1.891 Bq/kg; all obtained values are under the action limit of (370 Bq/kg) declared by [1].

4.3 Indoor Absorbed Gamma Dose Rate (D_{in})

In order to convert the specific activities to an indoor dose rate (D_{in}) the conversion factors of 0.92, 1.1 and 0.081 nGyh-1/Bq.kg^{-1} are used for ^{226}Ra, ^{232}Th and 40K respectively, thus it can be obtained using the following equation [15].

$$D_{in}(nGyh^{-1}) = 0.926A_{Ra} + 1.1A_{Th} + 0.081A_K \quad (3)$$

The calculated D_{in} for salt samples are tabulated in Table 4, column 3. The measured range of D_{in} varied from minimum 0.38 (S1) to maximum 4.418(S6) with arithmetic mean of 1.806 nGyh^{-1}. The calculated values are below the indoor dose reference limit of 84 nGyh^{-1} declared by [1].

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4.4 Indoor Annual Effective Dose Rate (E_{in}):

The indoor annual effective dose rate can be obtained from the indoor dose in air using the conversion factor of 0.7 Sv Gy^{-1} and the individuals remain in the indoor building with an average life of 80% during one year. The calculation of Ein was done using:

$$E_{in}(mSv\ y^{-1}) = D_{in}(nGyh^{-1}) \times 8760h \times 0.8 \times 0.7Sv\ Gy^{-1} \times 10^{-6} \quad (4)$$

The calculated Ein for the salt samples are presented in Table 4 column 4 and ranges from a minimum of 0.002 (S1) to a maximum of 0.022 (S6) with algebraic mean of 0.009 mSv.y^{-1} which is well below the safety recommendation value of 0.41 mSv.y^{-1} declared by [1].

4.5. Internal hazards index (H_{in}):

Internal hazards index can be used to determine the effect of alpha particles emitted from radon and its progenies that affects the respiratory organs especially lungs, which can be obtained from [16]; [14]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (5)$$

The evaluated H_{in} values are shown in Table 4, column 5. The internal hazard index varies from a minimum of 0.002 to a maximum of 0.013 with the average values were found to be 0.006. The calculated values are under the action limit of one. It can be concluded that, all the studied salt samples do not create radioactive risk to residents.

4.6. Annual Committed Effective Dose E_{ing}:

Annual effect dose arises from ingestion of food over a lifetime, it depends on the amount of food consumption during every day and the specific radionuclides involved and can be calculated as:

$$E_{ing}(Sv\ y^{-1}) = I \times A \times C \quad (6)$$

Where I: is the average amount of salts intake by adults (3.65kg/year) for one year) [17], A is the specific activities of salt samples in Bq/kg and C represents the ingestion dose factor which used to convert the activity to ingestion dose rate with values of 4.5×10^{-8}, 2.3×10^{-7} and 6.2×10^{-9} Sv/y for ^{226}Ra, ^{232}Th and ^{40}K respectively[18].

The (E_{ing}) calculated for the salt samples are presented in Table 4, column 6. It changes from minimum of 0.028 to a maximum of 2.287 with a mean value of 0.649 µSv.y^{-1}, which is below the recommended of 1000 µSv.y^{-1} [1].

TABLE 4. The radiological indices for ^{226}Ra, ^{232}Th and ^{40}K in salt samples.

Code	$Ra_{eq.}$ Bq/kg	D_{in} ($nGyh^{-1}$)	E_{in} (mSv/y)	H_{in}	E_{ing} µ sv/y	$ELCR_{ing}$ $*10^{-3}$
S1	0.399	0.380	0.002	0.002	0.078	0.0003
S2	3.157	2.658	0.013	0.009	1.547	0.0051
S3	1.570	1.508	0.007	0.005	0.527	0.0017
S4	0.529	0.508	0.002	0.002	0.108	0.0004
S5	1.981	1.873	0.009	0.006	0.691	0.0023
S6	4.554	4.418	0.022	0.013	1.628	0.0054
S7	1.777	1.660	0.008	0.006	0.650	0.0021
S8	0.630	0.615	0.003	0.003	0.139	0.0005

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S9	1.287	1.095	0.005	0.003	0.647	0.0021
S10	1.449	1.468	0.007	0.005	0.370	0.0012
S11	0.400	0.389	0.002	0.002	0.086	0.0003
S12	1.776	1.809	0.009	0.006	0.463	0.0015
S13	1.800	1.833	0.009	0.006	0.469	0.0015
S14	3.081	2.859	0.014	0.010	1.169	0.0039
S15	3.291	3.202	0.016	0.010	1.097	0.0036
S16	3.183	3.150	0.015	0.010	1.017	0.0034
S17	1.433	1.460	0.007	0.005	0.375	0.0012
S18	1.744	1.618	0.008	0.006	0.622	0.0021
Min	0.399	0.380	0.002	0.002	0.078	0.0003
Max	4.554	4.418	0.022	0.013	1.628	0.0054
Average	1.891	1.806	0.009	0.006	0.649	0.0021

Excess Life Time Cancer Risk (ELCR)

The excess life time cancer can be defined as the probability of occurring and appearing cancer from ingestion doses and can be estimated by:

$$(ELCR)_{ing} = E_{ing} \times LE \times RF \quad (7)$$

Where (Eing), LE and RF(Sv^{-1}) are the annual effective doses, individual expected life time (66 years) and fatal risk factor per Sievert (0.05), respectively [19] .

The results are presented in Table 3, column 7. The range of $ELCR_{ing}$ varies from a minimum of 0.0003 $\times 10^{-3}$ (S1) to a maximum 0.0054×10^{-3} with an algebric mean of 0.0021 $\times 10^{-3}$. The obtained values are well below the average recommendation worldwide value of 1.45×10^{-3} declared by [1].

Statistics of Pearson correlation coefficient

(SPSS) is a statistical useful tool used to determine the correlation relationship between the activities of primordial radionuclide and the derived radiological index. This relationship was established on the basis of using the Pearson correlation coefficient analysis and tabulated in Table 5.

The calculated coefficients show that there is a negative correlation between ^{238}U and ^{232}Th which indicates to different sources of the two radionuclides. On the other hand, there was a weak and positive relation between ^{226}Ra and ^{40}K revealing their same origin and contribution to the derived doses. The strong relationship between all indices with both ^{232}Th and ^{40}K certifies that the calculated doses are controlled by both radionuclides, while a weak positive relation for ^{226}Ra indicates its less contribution to the total doses.

TABLE 4. Pearson correlation coefficients between natural radionuclides and derived radiological indices.

Variables	**^{226}Ra**	**^{232}Th**	**^{40}K**	**$Ra_{eq.}$**	**D_{in}**	**E_{in}**	**H_{in}**	**E_{ing}**	**$ELCR_{ing}$**
^{226}Ra	1								
^{232}Th	-0.205	1							
^{40}K	0.512*	0.281	1						
$Ra_{eq.}$	0.352	0.687**	0.886**	1					

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D_{in}	0.405	0.609**	0.928**	0.995**	1				
E_{in}	0.411	0.605**	0.928**	0.993**	0.999**	1			
H_{in}	0.463	0.624**	0.901**	0.989**	0.991**	0.991**	1		
E_{ing}	0.143	0.867**	0.720**	0.957**	0.923**	0.921**	0.923**	1	
$ELCR_{ing}$	0.199	0.834**	0.731**	0.954**	0.923**	0.922**	0.924**	0.983**	1

5. CONCLUSIONS

The specific activities of three primordial radionuclides in cooking salt samples available in local markets of Kurdistan region have been determined. The highest radium equivalent is found in Altunsara produced in Iraq while the lowest found in Khosh produced in Turkey. Fortunately, all obtained values are well below the recommendation values declared by WHO and UNSCEAR and are in the limit of safe consumption. Statistics of multivariate analysis of Pearson correlation has been performed. Statistically, the strong positive correlation between the derived indices and primordial radionuclides indicates that the doses produced are dependent on three radionuclides, especially loaded on both ^{232}Th and ^{40}K. It was recommended that individuals prepare their meals every day using the khosh salt varieties.

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