ORIGINAL ARTICLE

Assessment of Radiation Risks and Statistical Evaluation of Natural Radioactivity in Typical Fertilizer Types

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Abstract

Purpose: The application of fertilizers raises concerns regarding their potential to increase natural soil radioactivity, attributed to radioactive elements found in specific types of fertilizers. The purpose of this work is to assess the natural radioactivity levels of different fertilizers by measuring the concentrations of radionuclides ^{226}Ra, ^{232}Th, and ^{40}K and other risk factors using a High-Purity Germanium (HPGe) detector with 50% relative efficiency, and to complete this assessment, eight fertilizer samples were collected and were dried, crushed, and sieved for homogenization.

Materials and Methods: They were then sealed in Marinelli beakers (type 533N) and were stored for gamma spectroscopy analysis. Furthermore, SPSS software was employed for data analysis, applying cluster analysis, Pearson correlation, basic statistical evaluations, and multivariate statistical techniques to explore relationships among the radionuclides and hazard indices.

Results: To assess potential radiological health risks, several radiation hazard indices were calculated and ranging between (119.39-17.59) Bq/Kg for the Radium Equivalent Activity (Raeq), (0.32- 0.05) for External Hazard Index (Hex), (0.42- 0.06) for Internal Hazard Index (Hin), (0.07-0.01) mSv/year for Annual Effective Dose Equivalent (AEDE), (57.07- 8.71) nGy/h for D, (0.89- 0.13) for Gamma Index (Iγ), (0.40- 0.01) mSv/year for Annual Gonadal Dose Equivalent (AGDE), ((0.24- 0.06) 10^{-3} for Excess Lifetime Cancer Risk (ELCR),(56.98- 7.85) W/kg for Radioactive Heat Production Rate (RHP). These levels stay within the specified and appropriate boundaries, except the AGDE risk for the Perlite Saudi. The results also indicated the levels in Bq/kg of measured radionuclides for all samples ranging between (54.3±28.4- 6.2±2.3) for ^{226}Ra, (29.2±6.4- 2.1±0.3) for ^{232}Th, and (551.2±38.1- 99.3±11.6) for ^{40}K.

Conclusion: The results indicate that the analyzed fertilizers do not present significant radiological health risks to humans or the environment, with radiation hazard factor levels remaining below the global average limits set by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

Keywords: Fertilizers; Gamma Spectroscopy; Natural Radioactivity.

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1. Introduction

Fertilizers are used to enhance agricultural soil to maintain soil fertility and boost output [1]. Cultivation media including peat moss, perlite, and hormones are used as soil conditioners to improve aeration, change the substructure of the soil, and enhance the soil's ability to hold water and nutrients [2]. Natural radionuclides found in our atmosphere include the radioactive gas radon, potassium (^{40}K), and the 238U and ^{232}Th series and with decay [3, 4]. Natural radioactivity varies depending on the type of fertilizer; the widespread use of fertilizers is one of the causes of radiation above the natural level [5]. Chemical fertilizers exist in many kinds of forms, and due to differences in their manufacturing processes and the locations from where they were produced, these varieties differ greatly in terms of radioactivity [6, 7]. Fertilizers include radionuclides that pollute agricultural lands and the environment. The distribution of fertilizers in the soil has the potential to expose living things to radionuclides. Numerous factors, including negotiable Ca and K, soil pH, organic matter contents, clay kind and quantity, radionuclide physicochemical properties, climate conditions, fertilizer application, crop type, irrigation, cultivating, liming, and affect how radionuclides are absorbed and distributed in the soil [8]. This research focuses on evaluating how fertilizers influence natural radioactivity in agricultural soils. The study investigates the potential impact of fertilizer application on radioactive concentration. It aims to analyze the relationship between fertilizer use and natural soil radioactivity levels.

2. Materials and Methods

2.1. Sampling and Samples Preparation

Samples of several fertilizers were purchased from the markets in Iraq. After sample collection, they were dried for six hours at about 200 degrees Celsius in an oven, lower drying temperatures resulted in fertilizer clumping, which affected sample handling and consistency. In contrast, increasing the drying temperature (200ºC) improved long-term storage stability, ensured complete moisture removal, and minimized the potential for data distortion due to water content. This approach allowed for more accurate measurements of the elements under investigation. The samples then being crushed and homogenized by sieving through a 200 μm mesh screen. To attain a secular balancing between the samples' radium and thorium concentrations as well as their daughter radionuclides, the samples were properly sealed in a Marinelli beaker type 533 N. The Marinelli beaker 533N is used to seal fertilizers for gamma spectroscopy, minimizing radiation loss and scattering. It ensures accurate detection of low radioactivity, prevents contamination, and safely contains radiation and particles, the samples have been weighed at 500 grams, and stored for four weeks [9].

2.2. Measurement of Natural Radioactivity

The study used Gamma-ray spectrometry for the measurement procedure. The system consists of a high-performance multichannel analyzer, the digital spectrum analyzer model (DSA-2000) (CANBERRA, USA), and an HPGe detector (HPGe detector with 50% relative efficiency is typically used in applications where high-resolution gamma spectroscopy is required). Through Ethernet, a personal computer managed the system, and Geany-2000 software (Canberra Industries, USA) was used to gather and store the data for further analysis. By using lead bricks to protect the detector, the background radiation levels were decreased. The detector's relative efficiency for detecting natural radioactivity in samples is 50%, and its energy resolutions reach 2.2 keV. This happens at 1332.5 keV gamma emission of ^{60}Co. Used a standard Marinelli beaker to calibrate the relative efficiency of the full energy peak containing ^{241}Am, ^{57}Co, ^{60}Co, ^{88}Y, ^{85}Sr, ^{137}Cs, ^{109}Cd, ^{203}Hg, and ^{139}Ce sources. A total activity of 1.1 μCi was recorded, along with the Marinelli beaker's mass (492.5 g), with a density that could be 0.985 ± 0.01 g cm^{-3}, and 500 ± 5.0 cm^3. Each sample had a dead time range of 0.08% to 0.3%, and the counting time was 7200s.

By detecting the gamma radiation from the isotopes ^{226}Ra (186.2 keV), ^{214}Pb (351.9 keV), and ^{214}Bi (609.2 keV) at energies and radioactivity of ^{238}U was determined. The activity of ^{232}Th at 583.1 keV and 911.1 keV of the isotopes ^{208}Tl and ^{228}Ac, in respect, was thus found by the gamma emission investigations. One peak, 1460 keV, was used to calculate the radioactivity of ^{40}K [10].

In the samples, for determining the radioactivity of natural radionuclides (for ^{238}U series, ^{232}th series, and ^{40}K) by Equation 1 [11]:

$$A = \frac{(\sum N - \sum B.G)}{(eff.I\gamma.t.m)} \quad (1)$$

where A is the active consternation, ∑ N is the net peak of energy peak, ∑ B.G. is its background (B.G.), eff is the efficiency calibration, Iγ the absolute intensity, t (time), and then after it comes m (the sample weight).

Detector efficiency calibration is determining how effectively a radiation detector measures the radiation emitted from a sample. It involves determining the relationship between the true activity of a sample and the measured count rate or signal from the detector. The efficiency calibration process is made by placing a well-known radioactive source activity near the detector. This source should emit radiation in the same energy range as the target radiation for accurate calibration. The detector is used to measure the counts from the standard source over a known period and finally, the measured count rate is compared to the known activity of the source to determine the detector's efficiency [12].

The Minimum Detectable Activity (MDA) is the lowest radioactive nuclide which the system measures, so it is important to find (MDA) of each radioisotope calculated by Equation 2 [11]:

$$MDA(Bq) = \frac{(2.7 + 4.65(BG)1/2}{(eff.I\gamma.t)} \quad (2)$$

The measured MDAs for ^{226}Ra, ^{232}Th, and ^{40}K reached 0.21, 0.13, and 1.04 Bq, respectively.

2.3. Calculation of Radiological Influences

Ra_{eq}

The following Equation 3 is used to determine this factor to reveal the uniformity in the radionuclide's radioactivity distribution [13].

$$Ra_{eq}\left(\frac{Bq}{Kg}\right) = A_{Ra} + 1.43\,A_{Th} + 0.077A_K \quad (3)$$

Here, A_{Ra}, A_{Th}, and A_K refer to precise activity consternation of ^{226}Ra (370 Bq/ kg), ^{232}Th (259 Bq/ kg), and ^{40}K (4810 Bq/ kg) in Bq/Kg. For obtaining the same gamma doses, it has been assumed that and for ^{226}Ra, ^{232}Th, and ^{40}K in a row.

Radiation Hazard Index: we calculated H_{ex} for limiting the external gamma radiation by Equation 4 [14].

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} < 1 \quad (4)$$

Hin can be calculated by Equation 5 [14]:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

H_{ex} equals a unity corresponding to the Ra_{eq} upper limits (370 Bq/kg).

Gamma Index (I_γ):

This indicator is calculated by Equation 6 [15].

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{259} + \frac{A_K}{1500} \leq 1 \quad (6)$$

The maximum values of these indicators Hex, Hin, and I_γ must be lower than a unit; at this unit, the radiation hazard is negligible.

The Absorbed Dose Rate in Air (D) (Equation 7) [16].

$$D\left(\frac{ngy}{h}\right) = 0.462A_{Ra} + 0.604A_{Th} + 0.042A_K \quad (7)$$

Here, 0.43, 0.67 and 0.042 nGy/.h are the conversions for ^{226}Ra, ^{232}Th, and ^{40}K, in respect.

Annual Effective Doses Equivalent (AEDE)

The study used Equations 8 and 9 for the computation of the annual effective dose equivalent for outdoor and indoor utilizing factor 0.7 SvGy^{-1}, utilized for the conversion of the absorbed doses to human active ones 20% for outdoor and 80% for indoor [17].

$$(AEDE)Outdoor\ (\mu Sv/y) = D\ (nGy/h) \times 8760\ h \times 0.2 \times 0.7\ Sv/Gy \times 10^{-6} \quad (8)$$

$$(AEDE)Indoor\ (\mu Sv/y) = D\ (nGy/h) \times 8760\ h \times 0.8 \times 0.7\ Sv/Gy \times 10^{-6} \quad (9)$$

Excess lifetime cancer risk (ELCR) [18].

Even with small radiation exposures, the risk of developing cancer increases until the dose reaches more than 100 mSv. The following Equation 10 was utilized to compute this:

$$ELCR = AEDE \times LT \times RF \quad (10)$$

R.F. is a risk factor, whereas L.T. is a lifespan (70 years). According to Sievert (0.05 Sv^{-1}), the risk aspect is dying possibility due to cancer.

AGDE [19].

The quality of live cells determines the radiation effect. Therefore, UNSCEAR focuses on the gonads, bone surface cells, and active bone marrow by Equation 11:

$$AGDE\ (\mu Sv/\ year) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_K \quad (11)$$

RHP [20].

A portion of the energy produced by the radioactive isotopes' decay is transformed into heat, all radioactive isotopes generate heat, and most of them are ignored except the ^{238}U, ^{232}Th involvement, and ^{40}K, this unit is measurable by Equation 12:

$$\mathrm{RHP}\ (\mu \mathrm{Wm}^{-3}) = 10^{-5}\ \rho\ (9.52\mathrm{CU} + 2.56\mathrm{CTh} + 3.48\mathrm{CK}) \quad (12)$$

Here, ρ refers to the sample density (in kg/m^3), C.U. and CTh are the activity concentration ^{238}U, ^{232}.Th in ppm, and C.K. the activity concentration of ^{40}K in %. Using conversion factors changes the units of concentrations of the activities from Bq/kg to ppm or % [21].

3. Results

3.1. Activities Belonging to Concentrations

The radioactive isotopes ^{226}Ra, ^{232}Th, and ^{40}K have activity concentrations (6.2±2.3 to 54.3±28.4 Bq/kg, 2.1±0.3 to 29.2±6.4) Bq/kg, and 99.3±11.6 to 188.5±14.1 Bq/kg, respectively as shown in Table 1. The UNSCEAR-recommended limits were used as thresholds for all indices [22]:

3.2. Radiological Effects

Table 2 shows the calculated assessment of radiation hazards. The calculated radium equivalent activities (Ra_{eq}) due to the natural concentrations of radionuclide activities (^{226}Ra, ^{232}Th, and ^{40}K) from samples were in the range of (17.59 - 119.39) Bq/ kg. The biggest Ra_{eq} was 119.39 Bq/kg, smaller than the threshold values (370 Bq/ kg) [23]. The radiation hazard indices were (0.05 - 0.32) and (0.06-0.42) and the mean values for Outside and inside hazards were 0.32 and 0.42. The radiation threat was disregarded because the indicator's value was less than unity. The range of air absorbed gamma radiation dose rate (D), the gamma Index ($\boldsymbol{I_\gamma}$), $AEDE_{in}$, ELCR, AGDE, $AEDE_{out}$, and RHP are (0.13-0.62), (8.71-40.80) nGy/h, (0.01- 0.05) µSv/y, (0.04 - 0.20) µSv/y, (0.04-0.17), (0.01-0.28) mSv/y and (7.85-56.98) *10^{-5} μWm^{-3} respectively. The highest values of these indicators are (0.62, 40.80nGy/h, 0.05µSv/y, 0.20µSv/y, 0.17, 0.28 mSv/y and 56.98 *10^{-5} μWm^{-3}, respectively.

3.3. Multivariate Statistical Analysis

Using multivariate statistical analysis, which includes cluster analysis by SPSS software, Pearson correlation, and basic statistical analyses, the relationship between the radioactivity factors is described.

3.3.1. Basic Statistical Analysis

As indicated in Table 3, the statistical features of the radionuclide activities were described using fundamental statistical concepts including standard deviation, skewness, variance, kurtosis, median, mean, min., and max. The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K show a highly irregular distribution. This is indicated by the standard deviations being smaller than the mean values, suggesting variability in the data but not extreme dispersion. For the Skewness Analysis there is a positive skewness (^{40}K and ^{232}Th) indicating that their distributions are asymmetric, with a longer tail extending toward higher values. This suggests that while most samples have moderate activity levels, a few have significantly higher concentrations. A negative Skewness (^{226}Ra) indicates that its distribution is lopsided towards lower values, meaning there are occasional samples with much lower activity

Table 1. The activity of ^{226}Ra, ^{232}Th, ^{40}K in different samples

Fertilizers	1	2	3	4	5	6	7	8	9
	Perlite Saudi	Alfayafy	Culvita	Alassala	Green fresh	Gulf	Chift Chiler	Potgrond	Average in world
^{226}Ra Bq/kg	35.2±13.4	37.7±17.6	39.7±25.3	14.1±2.8	17.5±3.4	14.3±3.4	54.3±28.4	6.2±2.3	87±8
^{232}Th Bq/kg	29.2±6.4	6.1±1.8	4.3±1.8	4±0.4	11.2±0.9	6.4±1	13.3±3.9	2.1±0.3	87±8
^{40}K Bq/kg	551.2±38.1	106.8±16.5	114.3±16.5	188.5±14.1	153±13.2	99.3±11.6	181.8±20.7	109±10.8	4860±250

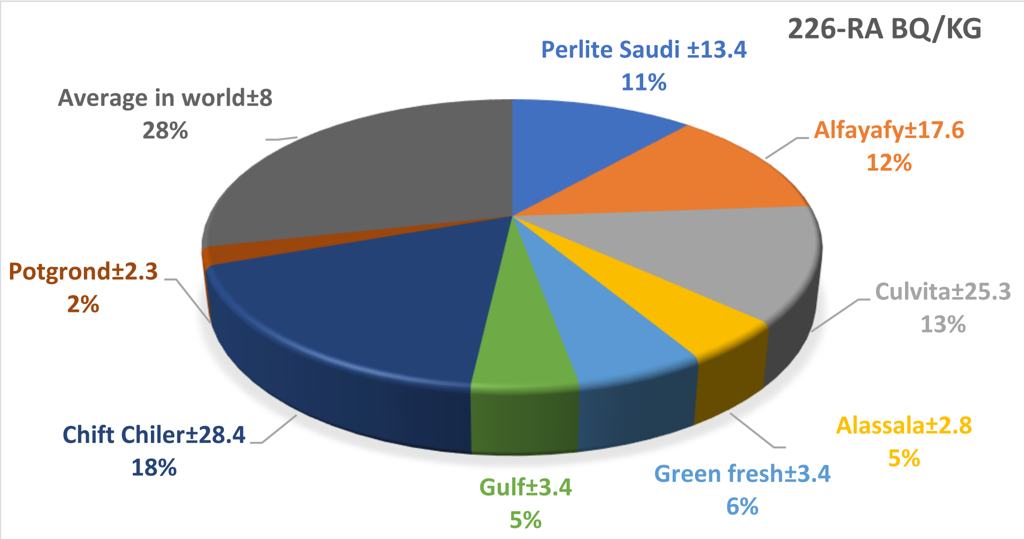

Figure 1. Comparison of 226-radon in Bq/kg levels of the UNSCEAR-recommended limits with all fertilizers types used in this work

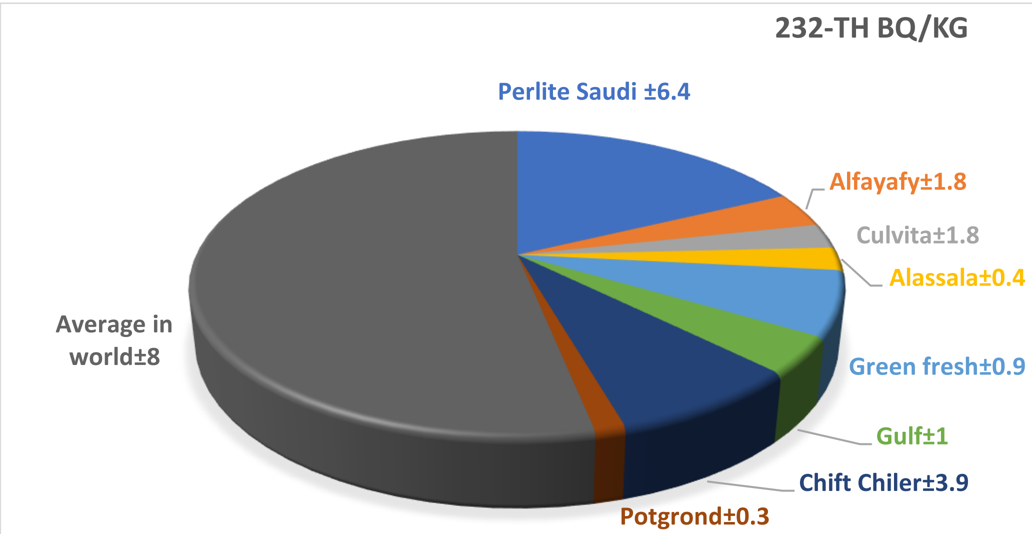

Figure 2. Comparison of 232- Thorium in Bq/kg levels of the UNSCEAR-recommended limits with all fertilizers types used in this work

concentrations compared to the majority. The form is a normal distribution since the skewness is often modest [24]. This indicates that extremely low or high activity values are rare, and most samples have radioactivity levels close to the average.

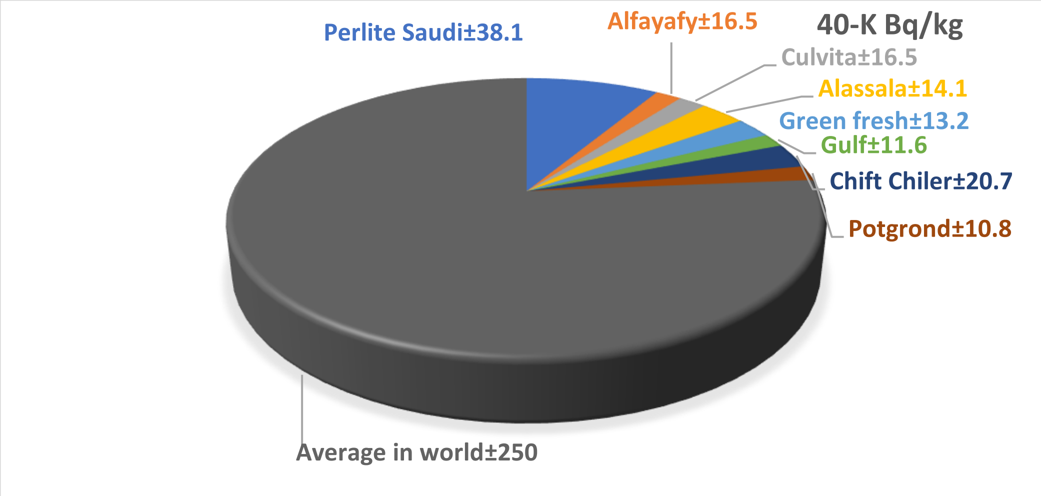

Figure 3. Comparison of 40- Potassium in Bq/kg levels of the UNSCEAR-recommended limits with all fertilizers types used in this work

Table 2. The Radiological Effects

Fertilizers	Ra_{eq} (Bq/kg)	H_{ex}	H_{in}	$I_γ$	D (nGy/h)	$(AEDE)_{Out}$ (µSv/y)	(AEDE)in (µSv/y)	ELCR x10^{-3}	AGDE mSv/y	RHP *10^{-5} µWm^{-3}
Perlite Saudi	119.39	0.32	0.42	0.89	57.07	0.07	0.28	0.24	0.40	54.73
Alfayafy	54.64	0.14	0.24	0.38	25.61	0.03	0.12	0.11	0.17	37.37
Cul vita	54.65	0.15	0.25	0.38	25.77	0.03	0.13	0.11	0.17	38.03
Alassala	34.33	0.09	0.13	0.26	16.86	0.02	0.08	0.07	0.11	16.71
Green fresh	45.30	0.12	0.17	0.33	21.29	0.03	0.10	0.09	0.14	23.77
Gulf	31.10	0.08	0.12	0.22	14.65	0.02	0.07	0.06	0.01	17.40
Chift Chiler	87.32	0.23	0.38	0.62	40.80	0.05	0.20	0.17	0.28	56.98
Pot grond	17.59	0.05	0.06	0.13	8.71	0.01	0.04	0.04	0.06	7.85
Average	55.54	0.15	0.22	0.40	26.35	0.03	0.13	0.11	0.18	31.60
World average	370	<1	<1	<1	55	<0.08	<0.42	0.29×10^{-3}	<0.3	53

Table 3. Descriptive statistical of radioactive isotopes

	^{226}Ra	^{232}Th	^{40}K
Mean	27.37	9.57	187.99
Median	26.35	6.25	133.65
Std. Deviation	16.64	8.77	150.86
Variance	276.82	76.94	22758.82
Skewness	0.33	1.92	2.54
Kurtosis	-1.16	4.00	6.74
Range	48.10	27.10	451.90
Minimum	6.20	2.10	99.30
Maximum	54.30	29.20	551.20

3.3.2. Pearson Correlation Analysis

The statistical test determines the statistical correlation or link of two constant variables is Pearson's correlation coefficient. The correlation coefficient values between ^{40}K and ^{232}Th are highly positive indicating a strong linear relationship. This suggests that as the radioactivity level of one increase, the other tends to increase as well. This could be due to co-occurrence in the same fertilizer types, and the correlation coefficient value of ^{226}Ra with ^{232}Th was shown a low degree- positive this suggests that while there is a slight tendency for their activity levels to increase together, the association is not strong. The correlation coefficient values of ^{226}Ra, and ^{232}Th with ^{40}K are seen as a (medium correlation positive) indicates a moderate relationship, where changes in the activity of one radionuclide are somewhat associated with changes in the others.

3.3.3. Cluster Analysis

This study grouped the parameters into two statistical clusters, cluster I is radionuclides (^{232}Th and

^{40}K), and cluster II radionuclide ^{226}Ra and all-important radiological hazards as Figure 4 shows. For cluster analysis results showed that the concentration of ^{226}Ra contributed to the radiation hazarder more than the ^{232}Th ^{40}K. Natural radioactivity from the ^{226}Ra, ^{232}Th series, and ^{40}K generally does not present a radiation risk.

4. Discussion

Table 1 shows the highest ^{226}Ra level detected in the Chift Chiler fertilizer may be attributed to the raw materials used in its production, which could include phosphate known for its elevated uranium and radium content. The ^{232}Th and ^{40}K activity concentration was the highest in the Parite Saudi due to the inclusion of materials rich in thorium-bearing minerals and potassium compounds. However, all the samples' activity levels were below the UNSCEAR-recommended limits. Table 2. displays the radiological effects and risk factors for the eight fertilizers samples, according to the mentioned values, the levels stay within the specified and appropriate boundaries, therefore, the risky effects of their radiations are insignificant as in Figure 3. Except for the AGDE risk for the Perlite Saudi, it was more than the permissible limits (UNSCEAR) may be due

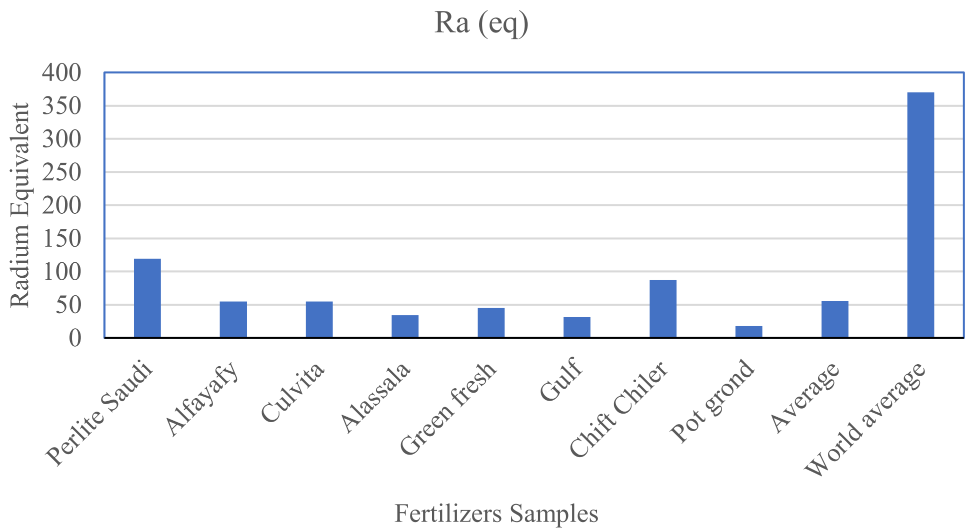

Figure 4. Comparison of the Radium Equivalent Activity (Ra_{eq}) of the Investigated fertilizer samples with the Worldwide Average Value (UNSCEAR-recommended limits)

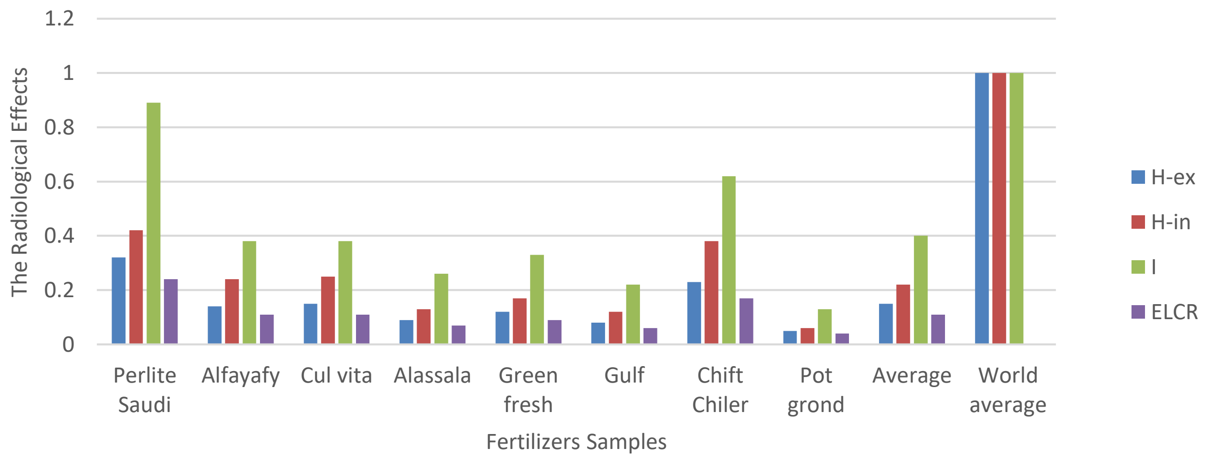

Figure 5. Comparison of the Radiation Hazard: External and internal Hazard Index (Hex, Hin), Gamma Index (Iγ), and Excess Lifetime Cancer Risk (ELCR) of the Investigated Fertilizer Samples with Worldwide Average Value (UNSCEAR-Recommended Limits)

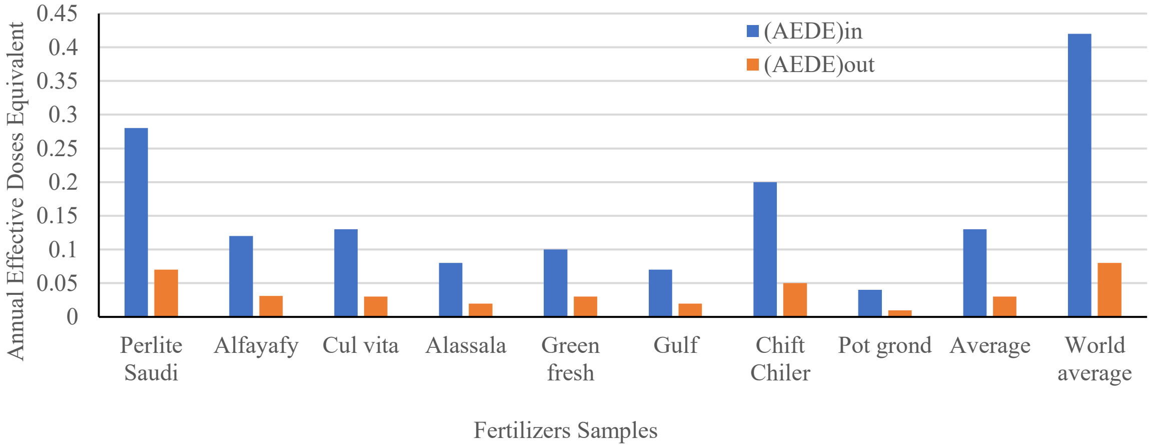

Figure 6. Comparison of the Annual Effective Doses Equivalent (AEDE)in and (AEDE)out with Worldwide Average Value (UNSCEAR-Recommended Limits) for the investigated fertilizer samples

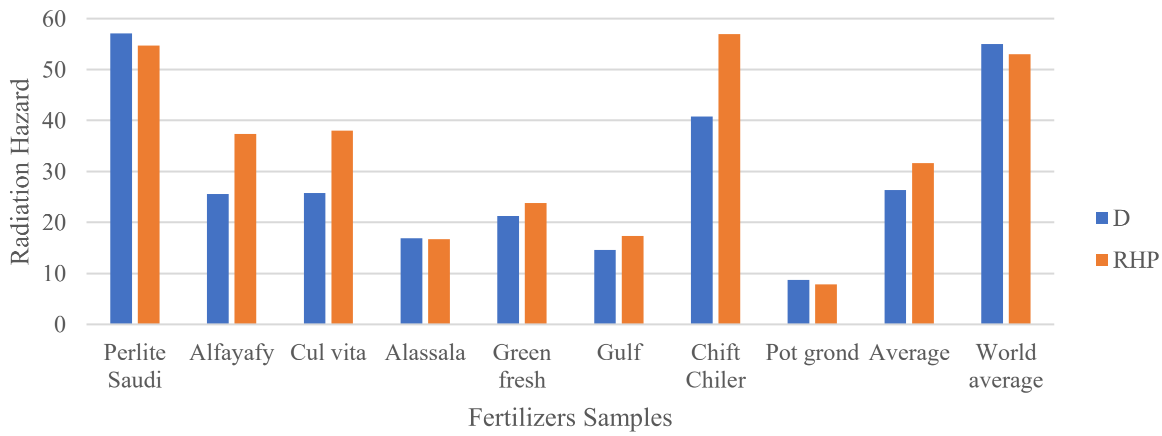

Figure 7. Comparison of Absorbed Dose Rates (D), the Radioactive Heat Production Rate (RHP) with the worldwide average value (UNSCEAR-Recommended Limits) for the investigated fertilizer samples

to the way the perlite is extracted, processed, or handled could potentially concentrate and release more radiation than expected that finally elevating the AGDE. Table 3 indicates that the curve achieved more peaks than the standard one because the kurtosis of the activity of ^{226}Ra and 40K are positive implying that their radioactivity levels are more concentrated around the mean, with a higher frequency of values close to the average and more pronounced peaks. This specifies less variability and fewer extreme outliers, meaning most samples show consistent activity levels for these radionuclides, whereas that of ^{226}Ra is negative.

Table 4 reflects a partial similarity in their environmental distribution or accumulation in the fertilizers, possibly due to shared sources or manufacturing processes. With regard to radiological

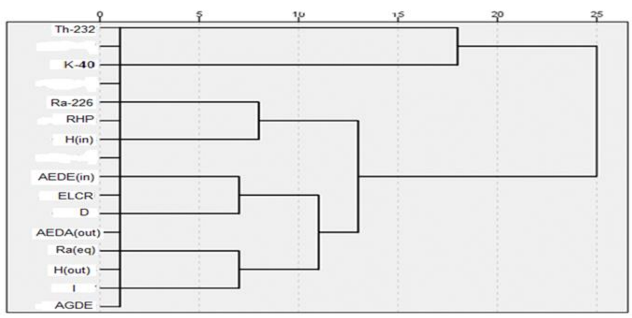

Figure 8. The two statistical clusters, cluster I is radionuclides (^{232}Th and ^{40}K), and cluster II radionuclide ^{226}Ra with radiological hazards

hazard parameters, the majority of ^{226}Ra, ^{232}Th, and ^{40}K correlation coefficient values are high correlations, while some medium correlations have positive correlation coefficients suggesting that the activity concentrations of these radionuclides

Table 4. Pearson correlation coefficients of radioactivity

	^{226}Ra	^{226}Th	^{40}K	Ra(eq)	Hex	Hin	Iγ	D	(AEDE) out	(AEDE) in	ELCR	AGDE	RHP
^{226}Ra	1												
^{226}Th	0.2794	1											
^{40}K	0.1486	0.931	1										
Ra(eq)	0.6555	0.8968	0.832	1									
Hex	0.6508	0.8964	0.837	0.9993	1								
Hin	0.8193	0.7709	0.679	0.9698	0.9681	1							
Iγ	0.6114	0.9159	0.863	0.9982	0.9979	0.954	1						
D	0.6391	0.9022	0.846	0.9996	0.9993	0.964	0.9993	1					
(AEDE)out	0.5989	0.9325	0.853	0.9951	0.9941	0.948	0.9965	0.995	1				
(AEDE) in	0.6466	0.895	0.842	0.9989	0.9996	0.966	0.998	0.9993	0.9924	1			
ELCR	0.6439	0.8986	0.843	0.9994	0.9992	0.965	0.9986	0.9997	0.9940	0.9988	1		
AGDE	0.6154	0.9125	0.862	0.9984	0.9983	0.956	0.9999	0.9995	0.9955	0.9985		1	
RHP	0.9055	0.6589	0.593	0.9127	0.9093	0.984	0.8874	0.9029	0.8820	0.9060	0.905	0.889	1

significantly influence the overall radiological risks (such as radium equivalent activity, absorbed dose rate, and hazard indices) [25].

The cluster analysis results indicate that ^{226}Ra contributes more significantly to the overall radiation hazard compared to ^{232}Th and ^{40}K. This can be scientifically explained by the fact that ^{226}Ra has a longer half-life and emits more biologically harmful alpha particles, which pose a greater internal radiation risk if ingested or inhaled. Additionally, ^{226}Ra tends to accumulate in bones due to its chemical similarity to calcium, increasing long-term exposure risks. However, despite ^{226}Ra's higher contribution to radiation hazards, the overall natural radioactivity from ^{226}Ra, ^{232}Th, and ^{40}K in the studied fertilizers remains below levels considered dangerous. This suggests that while ^{226}Ra has a greater potential impact on radiological risk, its concentration, along with that of ^{232}Th and ^{40}K, does not pose a significant radiation threat under normal exposure conditions [26].

5. Conclusion

Natural radioactivity was measured for eight types of fertilizers by a detector of a high-purity germanium. The radioactivity ^{226}Ra, ^{232}Th, and ^{40}K concentrations were within the internationally permissible limits of the UNSCEAR. Moreover, there is no risk to human health or the agricultural environment. Radiological effects like (Ra_{eq}, D, H_{ex}, H_{in}, Gamma Index Iγ, RHP, $AEDE_{in}$, $AEDE_{out}$, ELCR, and AGDE). The average of these parameters was calculated and proved within the internationally permissible limits with harmless radiation effects on the population and environments. The findings of this study have important practical implications for agriculture, highlighting the need for regular monitoring of natural radioactivity in fertilizers to ensure radiation exposure remains within safe limits. This information can guide selection and regulation of fertilizers with lower radiological risks, reducing potential health hazards for agricultural workers and consumers. It also emphasizes the importance of assessing long-term soil and crop contamination, supporting the development of safer fertilizer production methods, and sustainable agricultural practices.

5.1. Recommendation Future Works

Future research on radiation risks and natural radioactivity in fertilizers could focus on several key areas:

1- Investigation of long-term health effects of low-level radiation exposure on agricultural workers and nearby populations.

2- Studies on the bioaccumulation of radioactive isotopes in crops and their movement through the food chain.

3- Assess soil and groundwater contamination over a specific time due to fertilizer use.

4- Comparative studies between organic and synthetic fertilizers.

Researching safer than fertilizer alternatives, and employing bioremediation techniques to mitigate radioactive risks.

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