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Research Article
Natural Radioactivity Levels and Radiological Hazards in Soil Samples Around Abu Karqas Sugar Factory

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Abstract

Background and Objective: Soil contributes significantly to the internal and external exposure to environmental radioactivity by gamma rays and beta radiation that increase the risk to human health, therefore, the present study dealt with measuring radiation levels and radionuclides distribution (^{226}Ra, ^{232}Th and ^{40}K) for soil around non-nuclear industries by studying the effect of residues of Abu Karqas Sugar Factory on agricultural soil. **Materials and Methods:** Twenty five soil samples (N = 25) were collected from different locations around Abu Karqas Sugar Factory, Upper Egypt. Activity measurements have been performed by gamma-ray spectrometer, employing a high-resolution scintillation detector NaI (Tl) crystal 3×3 inch. Also multi-variate statistical analysis such as variance, skewness, kurtosis, Pearson correlation and cluster analysis was performed utilizing Statistics Software Bundle SPSS version 19.0 for Windows. In addition, the radiological hazards were calculated for the investigated samples. **Results:** The study indicated that, the average values of activity ranged from 8±0.7 to 33±2, 8±0.3 to 19±1 and from 111±4 to 209±12 Bq kg^{-1} for ^{226}R, ^{232}Th and ^{40}K, respectively. **Conclusion:** According to the obtained results, all samples would not present significant radiological hazards.

Key words: Abu Karqas Sugar Factory, agricultural soil, radiological hazard, upper Egypt, gamma-ray spectrometer

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

About 96% of the total radiation dose is from natural sources exists in various geological formations such as soils, rocks, sediments, vegetation, water and air, while 4% is of artificial origin[1]. Soil is the most important source of the terrestrial radionuclides whose activity concentrations depend primarily on the geological and geochemical conditions of each region in the world[2]. Terrestrial radionuclides contain the radioactive series of uranium-radium (^{238}U-^{226}Ra), thorium (^{232}Th) and radioactive potassium (^{40}K) in the earth's crust[3]. Long-term exposure to uranium and radium through inhalation has several health effects such as chronic lung diseases, acute leucopenia, anemia and necrosis of the mouth. Radium causes bone, cranial and nasal tumors. Thorium exposure can cause lung, hepatic, bone and kidney cancers and leukemia[4]. Hence, humans should be aware of their natural environment with regard to the radiation effects due to the naturally occurring and induced radioactive elements[5].

Soil contributes significantly to the internal and external exposure to environmental radioactivity by gamma rays and beta radiation that increase the risk to human health. The level of exposure depends on the climatic factors, fertilizing, local geology, drainage patterns which are different at each region in the world[6]. Therefore, the aim of the present research was to study the effect of residues of Abu Karqas Sugar Factory in Al-Ibrahimeh canal by measuring the concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the agricultural soil around the factory.

MATERIALS AND METHODS

Samples description: This study was done in the period between June-November, 2017. Twenty five samples of agricultural soil were collected from different regions around Abu Karqas Sugar Factory (Fig. 1). The samples coded by (S1-S25). Soil is a mixture of mineral and organic matter, the composition and proportion of these components greatly influence soil physical properties, including texture, structure

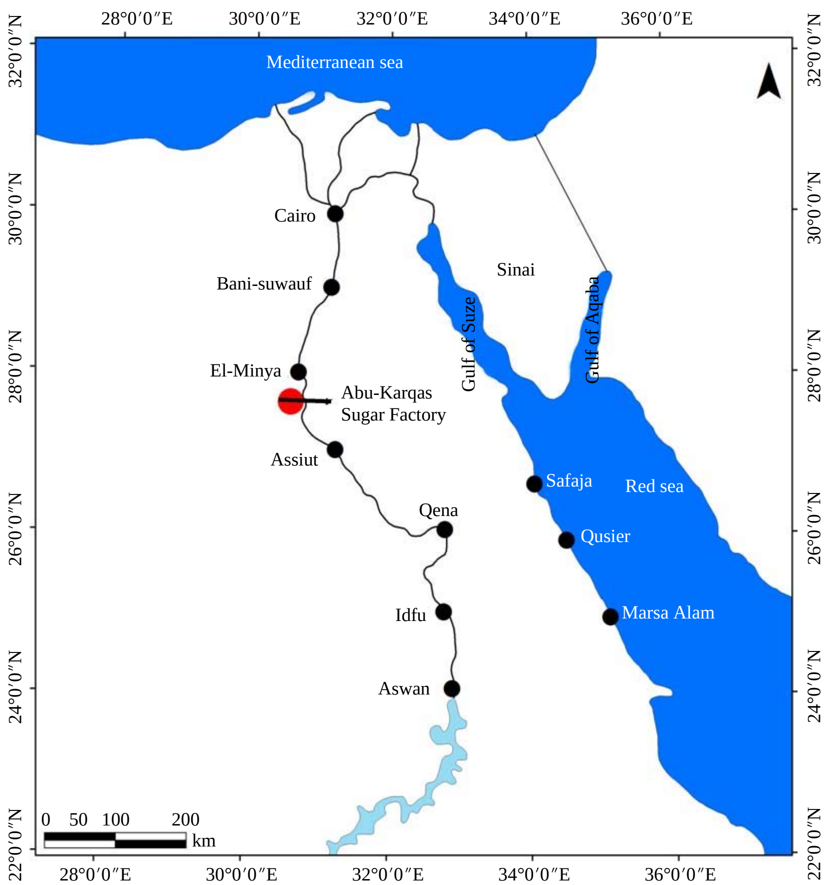

Fig. 1: Map showing the studied area

and porosity, the fraction of pore space in a soil and it is mainly made up of oxygen (46.7%), silicon (27%), aluminum (8.1%) and iron (5.0%).

Sample collection and preparation: The agricultural soil samples were collected by a coring tool to a depth of 5 cm or to the depth of the plough line[7]. The collected samples each were about 600 g in weight. All samples were dried in an oven at about 110°C for 24 h to ensure that moisture is completely removed. All samples were crushed, homogenized and sieved through a 200 μm, which was the optimum size enriched in heavy minerals. Samples were placed in polyethylene beaker, of 250 cm^3 volume each and weighted. The beakers were completely sealed for 4 weeks to reach secular equilibrium radium and thorium and their progenies[8,9].

Instrumentation and calibration: Radioactivity measurements were determined by using gamma ray spectrometer, employing a high-resolution scintillation detector NaI (Tl) crystal 3×3 inch. It had a hermetically sealed assembly, which included a NaI (Tl) crystal, coupled with a PC-MCA Canberra Accuspec. To decrease the gamma-ray background, a cylindrical lead shield (100 mm thick) with a fixed bottom and movable cover shielded the detector. The lead shield contained an inner concentric cylinder of copper (0.3 mm thick) in order to absorb X-rays generated in the lead[10,11]. In order to determine the background distribution in the environment around the detector, an empty sealed beaker was counted in the same manner and in the same geometry as the samples. The measurement time of the activity or background was 43,200 sec. The background spectra were used to correct the net peak area of the gamma rays of the measured isotopes. A dedicated software program was used Genie-2000. The detection array was energy calibrated using ^{60}Co (1173.2 and 1332.5 keV), ^{133}Ba (356.1 keV) and ^{137}Cs (661.9 keV). The curve of efficiency calibration was made using different energy peaks covering the range up to ~2000 keV. The ^{226}Ra radionuclide was predestined from the 351.9 keV γ-peak of ^{214}Pb and 609.3, 1120.3, 1728.6 and 1764 keV γ-peak of ^{214}Bi. The ^{232}Th radionuclide was predestined from the 911.2 keV γ-peak of ^{228}Ac and the 238.6 keV γ-peak of ^{212}Pb. The ^{40}K radionuclide was estimated using the 1461 keV γ-peak from ^{40}K itself[12-14]. For quality control, the uncertainties of the measured values have been calculated from all parameters.

Multivariate statistical analysis

Basic statistics: Statistical behavior of the measured data (range, minimum, maximum, sum, arithmetic mean (AM), arithmetic standard deviation (SD), variance, skewness, kurtosis and the type of frequency distribution for the three radionuclides for all the soil samples were performed utilizing Statistics Software Bundle SPSS version 19.0 for Windows. Skewness characterized the degree of asymmetry of a distribution around its mean[15,16]. Kurtosis is a measure of the peakedness of the probability distribution of a real-valued random variable. It characterizes the relative flatness or peakedness of a distribution compared with the normal distribution. Positive kurtosis indicates a relatively peaked distribution.

Pearson's correlation coefficient and cluster analysis: Cluster analysis and Pearson correlation were done keeping in mind the end goal to clear up the relationship among the factors, particularly the impact of dregs radiological parameters on the appropriation of common radionuclides. Principal components analysis (PCA) is the most common technique used to summarize patterns among variables in multivariate datasets. The PCA is a way of identifying patterns in variables and expressing data in such a way as to highlight their similarities and differences. The main advantage of PCA is that, once the patterns have been found, data can be compressed reducing the number of dimensions, without much loss of information[17].

RESULTS AND DISCUSSION

The distribution of the detected radionuclides, ^{226}Ra, ^{232}Th and ^{40}K and their corresponding total uncertainties for samples under investigation were listed in Table 1. While Fig. 2 shows a comparison between the activity concentrations in Bq kg^{-1} for all soil samples under investigation. From these results, the ^{40}K activity concentration dominated over that of the ^{226}Ra and ^{232}Th elemental activities. The highest value of activity concentration for ^{226}Ra was found in soil sample coded by (S15), while the lowest one was found in sample coded by (S17). For ^{232}Th values, the highest value of activity concentrations in soil sample coded by (S25), while the lowest value in soil sample code by (S12). In case of ^{40}K, the lowest value was found in soil sample code by (S25), while the highest one was in (S16) sample. The variation of radionuclides concentration in studied soil samples may be due to the geological and geographical conditions[18] and/or the using of chemical fertilizers. The worldwide average concentrations of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K, reported by UNSCEAR[19] are 35, 35 and 370 Bq kg^{-1}, respectively. The results showed that the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples were

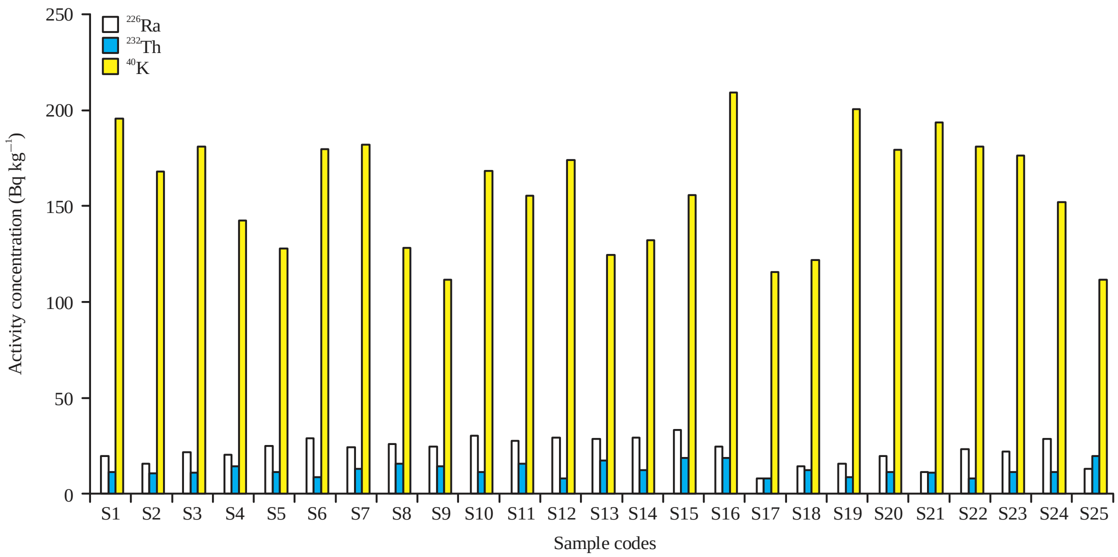

Fig. 2: Comparison between values of ^{226}Ra, ^{232}Th and ^{40}K activity concentration in Bq kg^{-1} for soil samples around Abu Karqas Sugar Factory

Table 1: Activity concentrations (Bq kg^{-1}) of ^{226}Ra, ^{232}Th and ^{40}K in soil samples around Abu Korqas sugar factory

Sample codes	Activity (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
S1	19±1.0	11±0.5	195±10
S2	15±1.0	10±0.5	168±8
S3	22±2.0	10±0.5	180±9
S4	20±1.0	14±0.8	142±7
S5	25±2.0	11±0.5	127±5
S6	29±2.0	9±0.4	179±9
S7	24±2.0	13±0.7	182±9
S8	26±2.0	15±0.8	128±5
S9	24±2.0	14±0.3	111±4
S10	30±3.0	11±0.5	168±9
S11	27±1.0	15±0.6	155±7
S12	29±2.0	8±0.3	174±9
S13	28±2.0	17±0.9	124±5
S14	29±5.0	12±0.6	131±6
S15	33±2.0	18±1.0	155±8
S16	25±2.0	18±1.0	209±12
S17	8±0.7	8±0.3	115±5
S18	14±0.7	12±0.6	122±5
S19	15±3.0	9±0.4	200±11
S20	19±11.0	11±0.5	179±9
S21	11±5.0	10±0.5	193±14
S22	23±2.0	8±0.2	180±6
S23	22±2.0	11±0.4	176±13
S24	28±5.0	11±0.5	152±10
S25	13±0.4	19±1.0	111±4
Minimum	8±0.7	8±0.3	111±4
Maximum	33±2.0	19±1.0	209±12
Average	22.32±2.0	12.2±0.6	158.24±8

^{40}K: Potassium, ^{232}Th: Thorium, ^{226}Ra: Radium

lower than the worldwide average concentrations. Table 2 shows a comparison of the radioactivity concentrations in the soil with other areas of the world.

Table 2: Comparison of the activity concentrations of the soil with other countries

Countries	Activity (Bq kg^{-1})		
	^{226}Ra	^{232}Th	^{40}K
India (Tamil Nadu)[20]	--	27-794.3	44-251.4
Egypt (El-Mynia)[21]	16.7	13.8	382
Saudi Arabia (Al-Qassim)[22]	--	2.5-39	212-915
Algeria[23]	53.2	50.03	311
Brazil (Panama)[24]	10.22	7.27	54.75
Egypt (Abou Zabal region)[25]	31.12	10.96	264.1
Saudi Arabia (El Taif)[26]	--	18.6	162.8
Niger (Jos Plateau)[27]	NM	734	115.8
Egypt (Alexandria)[28]	16.43	18.31	268.16
Pakistan(Pakka Anna)[29]	30-38	50-64	560-635
Egypt (present study)	22.32±2	12.2±0.6	158.24±8

^{40}K: Potassium, ^{232}Th: Thorium, ^{226}Ra: Radium

Statistical behavior of the measured data (range, minimum, maximum, sum, arithmetic mean (AM), arithmetic standard deviation (SD), variance, skewness, kurtosis and the type of frequency distribution for the three radionuclides for all the soil samples) presented in Table 3. The basic statistics show that the AM of activity concentrations are different from each other. The precipitation affects the natural radioactivity of the soils, when rain water mixed with SO_2 of the air, then rain become acidic. Acid rain causes accelerated mobilization of many materials in sediments, especially ^{238}U [30]. The highest value of AM was observed for ^{40}K (158.2 Bq kg^{-1}) and the lowest was for ^{232}Th (12.2 Bq kg^{-1}). The basic statistics showed that the AM of activity concentrations for all locations were different from each other.

The values of skewness and kurtosis for ^{226}Ra, ^{40}K and ^{232}Th were near to 0 and negative, respectively therefore, this

Table 3: Descriptive statistics of radiological parameters

Radioactivity variables	N	Range	Minimum	Maximum	Sum	Mean	SD	Variance	Skewness	Kurtosis	Frequency distribution
^{226}Ra	25	25	8	33	558	22.3	6.62	43.81	-0.55	-0.57	Normal
^{40}K	25	98	111	209	3956	158.2	30.13	907.61	-0.17	-1.25	Normal
^{232}Th	25	11	8	19	305	12.2	3.27	10.67	0.70	-0.45	Normal

SD: Standard division, ^{40}K: Potassium, ^{232}Th: Thorium, ^{226}Ra: Radium

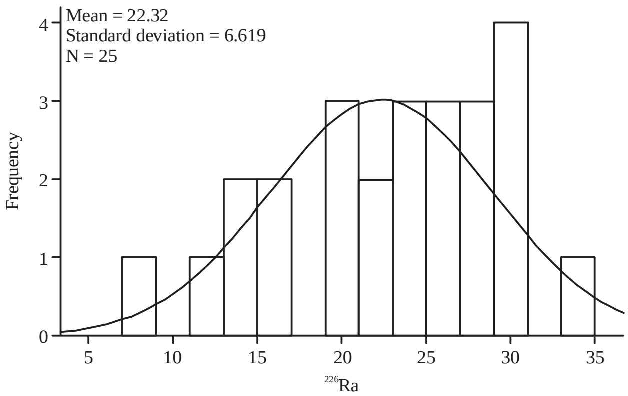

Fig. 3: Frequency distribution of ^{226}Ra

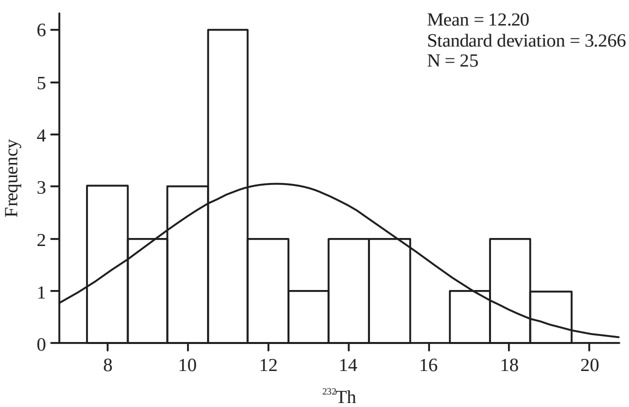

Fig. 4: Frequency distribution of ^{232}Th

radionuclide follows normal distribution. While positive skewness indicates a distribution with an asymmetric tail extending towards values that were more positive as observed in ^{232}Th but negative skewness indicated a distribution with an asymmetric tail extending towards values that were more negative as observed in ^{226}Ra and ^{40}K. Lower skewness value form generally normal distributions. Negative kurtosis indicated a relatively flat distribution (shown in this study case). Higher kurtosis means more of the variance was the result of infrequent extreme deviations.

The frequency distribution for a ll radioactive variables in sediment samples were analyzed, where the histograms given in Fig. 3, 4 and 5. The graph of ^{226}Ra and ^{40}K showed that these radionuclides demonstrate a normal

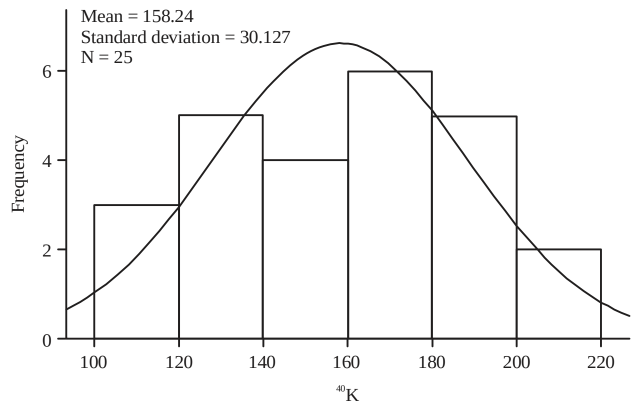

Fig. 5: Frequency distribution of ^{40}K

(bell-shape) distribution. But ^{232}Th exhibited some degree of multi-modality. This multi-modal feature of the radio elements demonstrated the complexity of minerals in sediment samples.

The results for Pearson correlation coefficients between all studied radioactive variables for soil samples shown in Table 4. From these results, the high good positive correlation coefficient was absorbed between ^{232}Th and ^{226}Ra because radium and thorium decay series occurs together in nature[31,21]. The positive correlation coefficient was absorbed between ^{226}Ra, ^{232}Th and ^{40}K with all the radiological parameters. This implied that there is very strong relationship between the radionuclides in soil and descriptive statistic.

Table 5 shows the results of data analyzed by graph pad prism 5 programs. As shown in Table 5, ^{232}Th was high, significantly different ($p<0.001$) from ^{40}K in the mean concentration activity, also ^{232}Th was significantly different from ^{226}Ra ($p<0.05$) in concentration activity. ^{226}Ra was high significantly different ($p<0.001$) from ^{40}K in the mean concentration activity.

Finally, cluster analysis was performed using average linkage method, to calculate the Euclidean distance between the variables. The derived dendrogram is shown in Fig. 6. In this dendrogram, all 6 parameters were grouped into five statistically significant clusters.

Radiological hazard indices

Radium equivalent activity (Ra_{eq}): The radium equivalent activity was used to obtain the sum of activities to compare

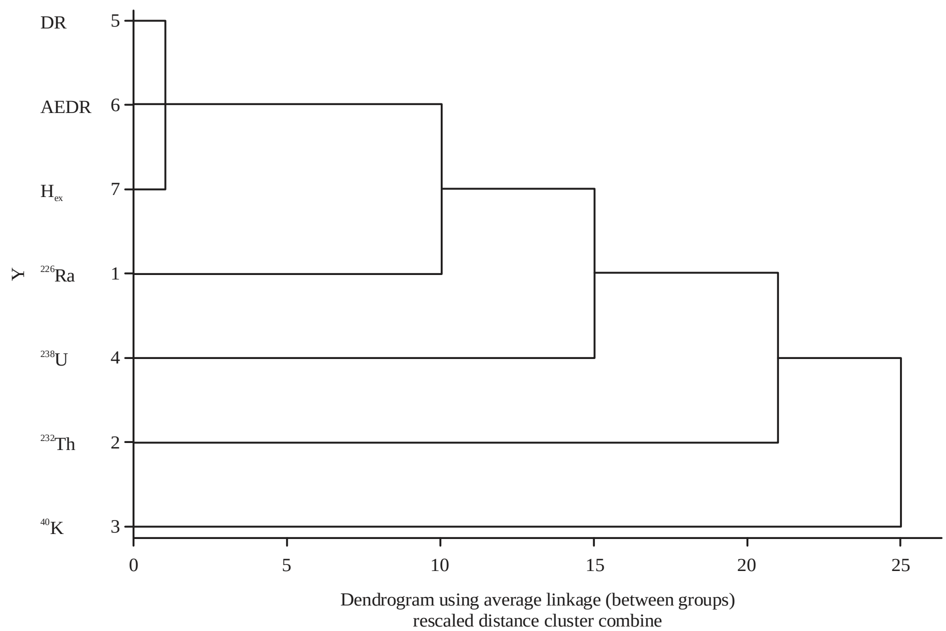

Fig. 6: Dendrogram shows the clustering of radionuclide sand their radiological parameters

Table 4: Pearson correlation coefficients between radioactivity variables in soil samples

Radioactivity variables	^{226}Ra	^{232}Th	^{40}K	D	AED	H_{ex}	I_γ
^{226}Ra	1						
^{232}Th	0.246	1					
^{40}K	0.041	-0.324	1				
D	0.857	0.612	0.179	1			
AED	0.857	0.612	0.179	1	1		
H_{ex}	0.877	0.618	0.120	0.998	0.998	1	
I_γ	0.863	0.600	0.186	1	1	0.998	1

H_{ex}: External hazard index, AED: Annual effective doses, I_γ: Gamma index, D: Absorbed gamma dose rate, ^{40}K: Potassium, ^{232}Th: Thorium, ^{226}Ra: Radium

Table 5: Results of data analyzed by graph pad prism 5 programs

Newman-Keuls multiple comparison test	Mean different	q	p<0.05	Summary
^{232}Th vs ^{40}K	-146.00	40.780	Yes	***
^{232}Th vs ^{226}Ra	-10.12	2.826	Yes	*
^{226}Ra vs ^{40}K	-135.90	37.950	Yes	***

***Very high significantly different at p<0.001, **High significantly different at p<0.01, *Significantly different at p<0.05, ^{40}K: Potassium, ^{232}Th: Thorium, ^{226}Ra: Radium

the activity concentration of soil samples, which contain ^{226}Ra, ^{232}Th and ^{40}K. The radium equivalent activities (Ra_{eq}) have been calculated on the estimation that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produces the same gamma ray dose rate. Therefore, the Ra_{eq} was given by Beretka and Mathew[32]:

$$Ra_{eq} = A_{ra}+1.43A_{Th}+0.077A_{k} \quad (1)$$

where, A_{Ra}, A_{Th} and A_K were the activities of ^{226}Ra, ^{232}Th and ^{40}K (Bq kg^{-1}), respectively. The results of radium equivalent activities (Ra_{eq}) for soil were presented in Table 6. From Table 6, it was observed that, the values of radium equivalent fluctuate from 27.49 Bq kg^{-1} in soil sample coded by (S17) to 69.59 Bq kg^{-1} in soil sample coded by (S15). These values were lower than the allowed maximum value[32] of 370 Bq kg^{-1}. Figure 7 showed the relative contributions to Ra_{eq} owing to ^{226}Ra, ^{232}Th and ^{40}K for soil samples. It was noticed that ^{226}Ra and ^{232}Th were the main contributor to Ra_{eq} in all samples.

Absorbed gamma dose rate (D): The measured activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were converted into doses by applying the conversion factors 0.462, 0.604 and 0.0417 for uranium, thorium and potassium[19], respectively. These factors were used to calculate the total dose rate (nGy h^{-1}) using the following equation:

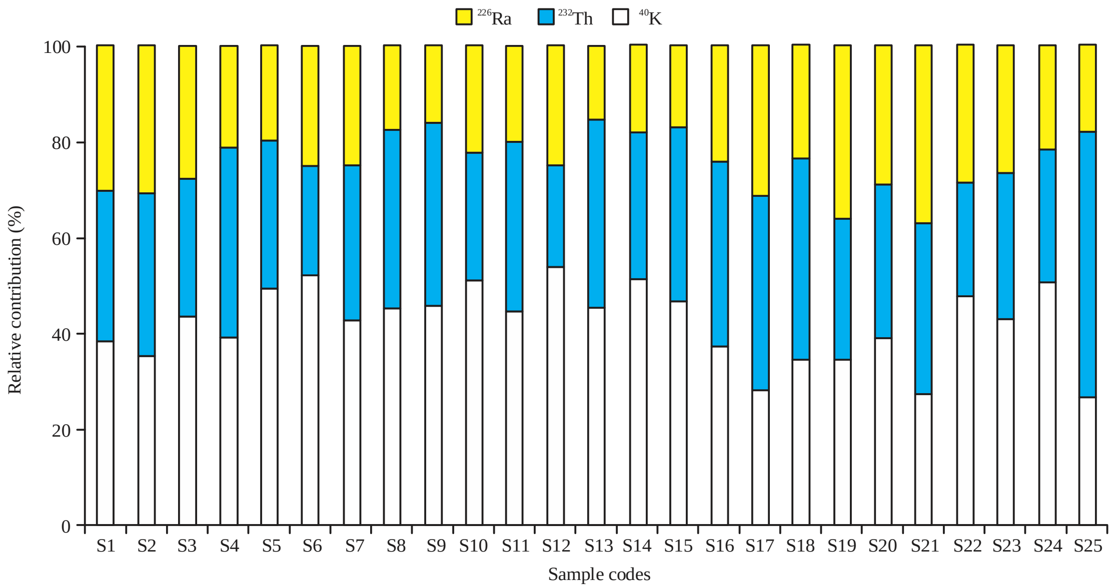

Fig. 7: Relative contribution (%) of ^{226}Ra, ^{232}Th and ^{40}K to Ra_{eq} in soil samples Abu Karqas Sugar Factory

Table 6: Ra_{eq}, D, AED and hazard indices (H_{ex}, H_{in}, I_γ and ELCR) for investigated samples

Sample codes	Ra_{eq} (Bq kg^{-1})	D (nGy h^{-1})	AED (µSv/year)	Hazard indices H_{ex}	H_{in}	I_γ	ELCR
S1	48.38	23.78	28.88	0.186	0.134	0.368	1.01E-04
S2	41.06	20.25	24.59	0.155	0.114	0.313	8.61E-05
S3	48.90	23.75	28.85	0.195	0.135	0.368	1.01E-04
S4	49.96	23.91	29.04	0.192	0.138	0.369	1.02E-04
S5	49.62	23.42	28.44	0.204	0.136	0.363	9.95E-05
S6	54.40	26.04	31.62	0.229	0.150	0.404	1.11E-04
S7	55.33	26.68	32.40	0.218	0.153	0.413	1.13E-04
S8	56.41	26.54	32.23	0.225	0.155	0.410	1.13E-04
S9	51.79	24.29	29.50	0.207	0.142	0.375	1.03E-04
S10	57.49	27.32	33.18	0.240	0.158	0.424	1.16E-04
S11	59.30	28.12	34.16	0.236	0.163	0.435	1.20E-04
S12	52.62	25.16	30.56	0.224	0.145	0.391	1.07E-04
S13	60.99	28.54	34.66	0.243	0.167	0.441	1.21E-04
S14	55.33	25.96	31.53	0.230	0.152	0.402	1.10E-04
S15	69.59	32.67	39.68	0.280	0.191	0.505	1.39E-04
S16	65.37	31.58	38.35	0.248	0.181	0.488	1.34E-04
S17	27.49	13.66	16.59	0.098	0.076	0.211	5.81E-05
S18	39.70	19.17	23.28	0.147	0.110	0.296	8.15E-05
S19	41.87	20.96	25.46	0.157	0.117	0.325	8.91E-05
S20	47.26	23.09	28.05	0.182	0.131	0.357	9.82E-05
S21	38.81	19.62	23.82	0.138	0.108	0.303	8.34E-05
S22	47.04	22.86	27.76	0.193	0.130	0.355	9.72E-05
S23	50.05	24.24	29.44	0.198	0.139	0.375	1.03E-04
S24	54.37	25.77	31.30	0.225	0.150	0.399	1.10E-04
S25	47.94	22.90	27.81	0.167	0.132	0.351	9.74E-05
Minimum	27.49	13.66	16.59	0.076	0.098	0.211	5.81E-05
Maximum	69.59	32.67	39.68	0.191	0.280	0.505	1.39E-04
Average	50.84	24.41	29.65	0.140	0.201	0.378	1.04E-04

Ra_{eq}: Radium equivalent activity, D: Absorbed gamma dose rate, AED: Annual effective doses, H_{ex}: External hazard index, H_{in}: internal hazard index, I_γ: Gamma index, ELCR: Excess lifetime cancer risk

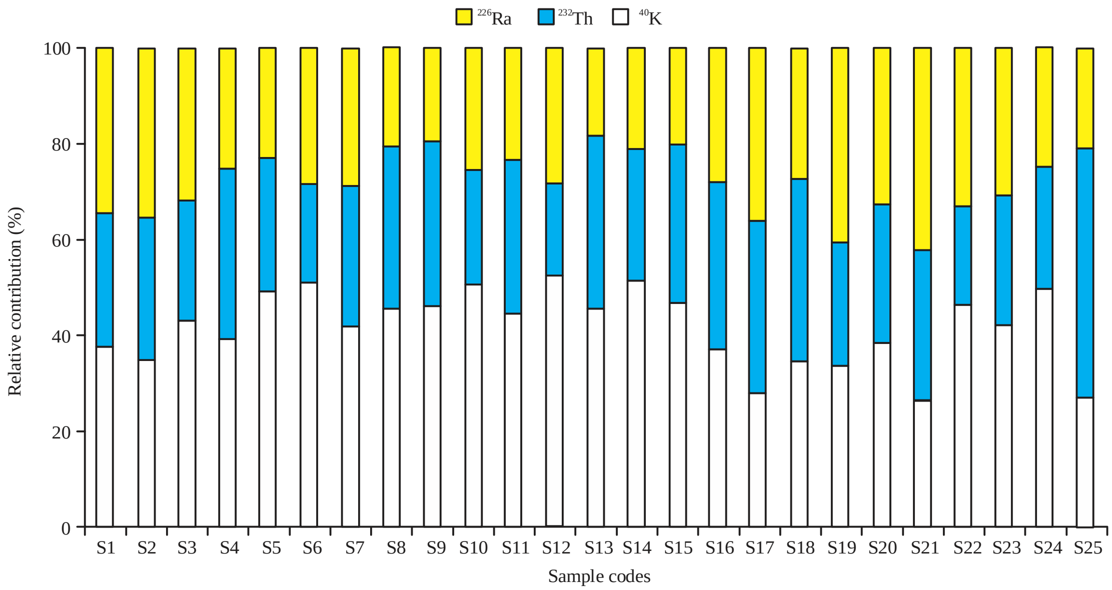

Fig. 8: Relative contribution (%) of ^{226}Ra, ^{232}Th and ^{40}K to D and AED in soil samples Abu Karqas Sugar Factory

$$D = 0.462A_{Ra}+0.604A_{Th}+0.0417A_K \quad (2)$$

where, A_{Ra}, A_{Th} and A_K has the same meaning as in Eq. 1. The calculated values of absorbed gamma dose rate for the samples were presented in column 2 of Table 6 and ranged from 13.66-32.67 nGy h^{-1}, those were lower than the allowed maximum value[19] of 59 nGy h^{-1}. The contributions to dose rate (D) and annual effective doses (AED) owing to ^{226}Ra and ^{232}Th higher than the contributions owing to ^{40}K, except in samples coded by (S19 and S21), the ^{40}K is highest one as shown in Fig. 8.

Annual effective dose (AED): The annual effective dose rate outdoors in units of (μSv/year) is calculated by the following formula[19]:

$$AED = \text{Absorbed dose (nGy h}^{-1})\times 8760 \text{ h}\times 0.7 \text{ Sv Gy/year}\times 0.2\times 10^{-3} \quad (3)$$

The AED values for the soil samples vary from 16.59-39.68 μSv/year, these values were lower than the world average values[33] at 70 mSv/year as observed in Table 6.

Hazard indices: Beretka and Mathew[32] defined tow indices that represented external and internal radiation hazards. The external hazard index (H_{ex}) was determined from the criterion formula as:

$$H_{ex} = \frac{C_{Ra}}{370}+\frac{C_{Th}}{259}+\frac{C_K}{4180}\leq 1 \quad (4)$$

where, C_{Ra}, C_{Th} and C_K are activities of ^{226}Ra, ^{232}Th and ^{40}K, respectively in Bq kg^{-1}. On the other hand, the internal hazard index (H_{in}) given the internal exposure to carcinogenic radon and its short-lived progeny and it was given by the following formula[32,33]:

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

where, A_{Ra}, A_{Th} and A_K having the same meaning as in Eq. 1. Table 6 showed that the calculated average values of hazard indices for all samples were less than unity[19], which did not cause any harm to the farmers and populations in region under investigation. Figure 9 shows the relative contributions to H_{in} owing to ^{226}Ra, ^{232}Th and ^{40}K for soil samples. As shown in Fig. 9, ^{226}Ra was main contributor to H_{in} in all soil samples.

Gamma index (I_γ): Another radiation hazard index called the representative level index, I_γ, was defined from the following formula[34], where, A_{Ra}, A_{Th} and A_K having the same meaning as in Eq. 1:

$$I_\gamma = 0.0067\ A_{Ra}+0.01\ A_{Th}+0.00067\ A_K \quad (6)$$

The calculated I_γ values for the samples under investigation were given in Table 6. It was cleared that the soil samples lower than unity[35]. Figure 10 showed the relative contribution to I_γ owing to ^{226}Ra, ^{232}Th and ^{40}k, from this figure ^{226}Ra was the higher contribution to I_γ in all

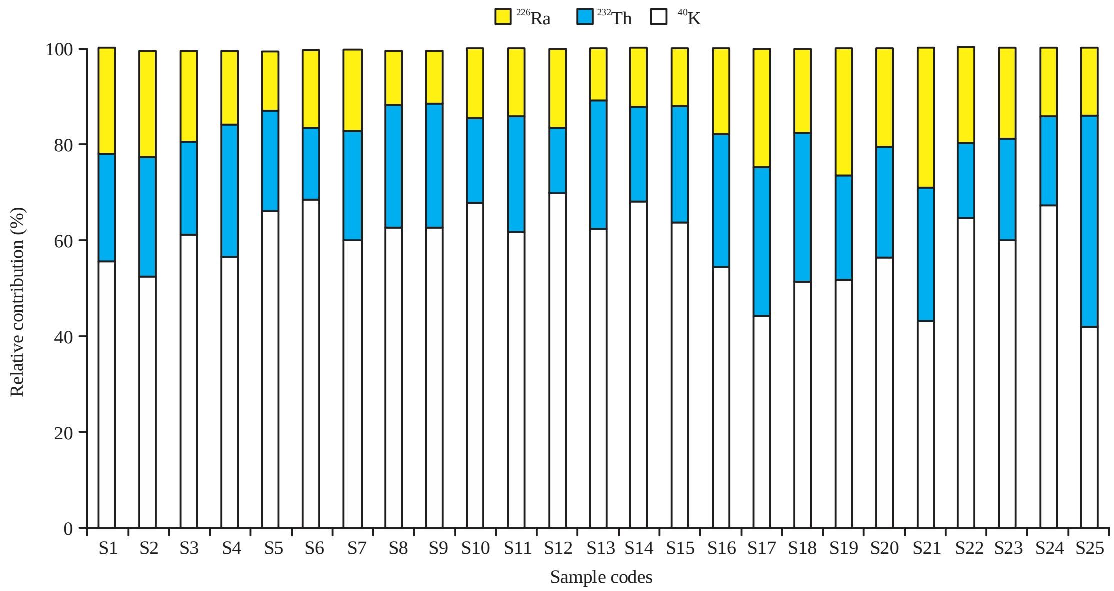

Fig. 9: Relative contribution (%) of ^{226}Ra, ^{232}Th and ^{40}K to H_{in} in soil samples Abu Karqas Sugar Factory

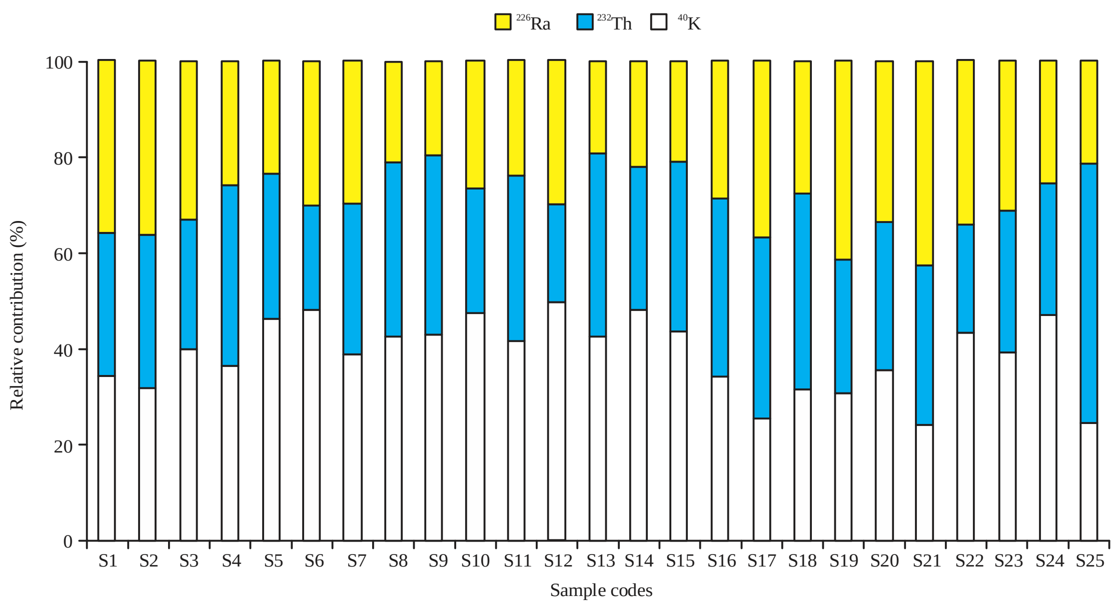

Fig. 10: Relative contribution (%) of ^{226}Ra, ^{232}Th and ^{40}K to I_γ in soil samples Abu Karqas Sugar Factory

soil samples, except in samples coded by (S18 and S25), ^{232}Th was the higher contribution.

Excess lifetime cancer risk (ELCR): Excess lifetime cancer risk (ELCR) could be defined as the excess probability of developing cancer at a lifetime due to exposure level of human to radiation. Excess lifetime cancer risk (ELCR) was calculated by using the following Eq.[36-41]:

$$\text{ELCR} = \text{EDR}\times\text{DL}\times\text{RF} \quad (7)$$

Where:

EDR = Annual effective dose equivalent

DL = Duration of life (30-70 years)

RF = Risk factor (Sv^{-1}) fatal cancer risk per Sievert. For stochastic effects, ICRP 60 uses values of (RF = 0.05) for public

The values of excess lifetime cancer risk (ELCR) for soil samples listed in Table 6. As shown in Table 6, it could be seen that, the values of excess lifetime cancer risk were ranged from 5.81E-05-1.39E-04, these values were less than the worldwide recommended value[16] of 29E-05.

The current study results showed that the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples were lower than the worldwide average concentrations. The variation of radionuclides concentration in studied soil samples may be due to the geological and geographical conditions[18] and/or the using of chemical fertilizers. It was recommended to reduce the dependence on chemical fertilizers to fertilize the soil, because these fertilizers contain high concentration of radioactive material, which may leads to health and environmental problems in the future.

CONCLUSION

As shown from the results, the activity concentration of naturally occurring radionuclides in soil samples around Abu Karqas Sugar Factory were within the world average ranges which are 35, 35 and 370 Bq kg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The radiological hazards in all soil samples were lower than the world average, so it is safe for farmers, population living and can be used as a building raw materials or other human activities without any radiological risk.

SIGNIFICANCE STATEMENT

This study discovers the natural radioactivity levels and associated radiation hazards in soil samples around non-nuclear industry. The novelty of the present study is evidence that there is no effect of non-nuclear industries on the concentrations of ^{226}Ra, ^{232}Th and ^{40}K for some environmental samples (soil), by studying the effect of residues of Abu Karqas Sugar Factory on agricultural soil.

This study is the first investigated in this area, so this study can be used as a baseline data for future investigations in pollution assessment and natural radioactivity mapping and could serve as a reference data for monitoring pollution studies in future.

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