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RESEARCH PAPER

Study of Radionuclides and Assessment of Radioactive Risks for Environmental Particulate Matters in Qassim Region, Saudi Arabia

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Abstract
The current research study the comprehensive health and environmental hazard levels of Particulate matter originating from natural radionuclides sources collected from different Qassim region locations, Saudi Arabia. The main goal is to determine the activity concentration for ^{226}Ra, ^{232}Th, and ^{40}K using a Sodium Iodide detector. Radiological parameters were calculated through the Radium equivalent, Gamma level index, absorbed dose, annual effective dose, and lifetime risk. The average activity concentration for ^{226}Ra, ^{232}Th, and ^{40}K is 35±0.06, 32.6±0.4, and 294.99±1.31 Bq/kg. Ra(eq) ranges from 38.3 to 143.1 with an average of 104.37 Bq/kg, absorbed dose ranges from 18 to 66.49 with an average of 48.18 nGy/h, and annual effective dose ranges from 22.09 to 81.58 with an average of 59.11 µSv/y. The relative contribution was 26%, 33%, and 41% for ^{40}K, ^{226}Ra, and ^{232}Th respectively. The obtained results do not cause apprehensions from the radiation population compatible with permissible public limits. These results consider as a database to predict the growth of radiological dangers. It helps the investigators follow the future pollution changes due to Scientific progress in using radioactive materials.

Keywords: Particulate matters; Radiological parameters; Health risk; Radionuclides.

INTRODUCTION

Particulate matters (PMs) are directly proportional to the respiratory system for human beings. (PMs) are intricate from organic and inorganic materials (Hueglin et al., 2005; Ulken et al., 2022). The particulate matter is classified according to geometric size and diameters. The first type is called the coarse particles (PMs_{10}), as its size is 10 microns or less, and the other type is called the fine particles ($PMs_{2.5}$) as its size is 2.5 microns or less (USEPA, 2011). IAEA, 2011. spotlight on environmental radioactive particles and their effect on human health during breathing and represent a risk for a long time. Moreover, a significant study of radioactive particles is due to undistributed radionuclides from the standard environmental system. They are resulted from nuclear diffusion activities in recent years and raised radioactive pollution. Ignore the presence of particulate matter, leading to inaccurate information (IAEA, 2011).

The physical-chemical properties of radionuclides related to particles are distinctive from that displayed within the shape of gasses or ionic types of soluble arrangements. The composition

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and the structure administer the properties of the particulate-bound radionuclides. Hence versatility, natural conduct, bioavailability, and biological of the radionuclides are fundamentally decided by the properties of (PMS) and environmental distribution. Therefore, health risks (IAEA, 2011; Mendell et al., 2011; Borràs-Santos et al., 2013). The desert and drylands around the Middle Eastern Promontory consider airborne particles sources, with a few commitments from Iran, Pakistan, and India into the Middle Eastern Ocean. As of late, it has been contended that destitute administration of the Earth's drylands, such as ignoring the neglected framework, are expanding tidy storms from leave edges and changing both the local and worldwide climate. Therefore, the economies will be affected. The Particulate matter can be transferred by storms and moved to 150 million metric tons (Roy, 1995; Ababneh et al., 2018).

The area under-investigated is characterized by active winds laden with particulate matter; it depends on the geological setting. The mobility of PM toxic elements is to raise pollution (Hueglin et al., 2005; Guo et al., 2004; Cheng et al., 2005). The normal distribution of radionuclides originated from terrestrial sources are varies according to geochemical and geophysical varies due to human futility, which leads to a defect from standard magnitudes (Mansour et al., 2017; Alashrah & EL-Taher, 2016; Chowdhury et al., 2006). Some radiation protection institutions recommended periodically measuring the naturally occurring radioactive materials to record the variance (UNSCEAR, 2000; IAEA, 2005).

The main goal of the current study is to determine the activity concentration for ^{226}Ra, ^{232}Th, and ^{40}K using a Sodium Iodide detector and concerned with hazard level measurements originating from atmospheric airborne particulate matters collected from different Qassim region locations, Saudi Arabia. Moreover, it provides us with information related to the distribution of other natural radionuclides.

MATERIALS & METHODS

Qassim region is in the center of Saudi Arabia, and its area is about 73,000 km^2. It represents 3.2% of the total area of Saudi Arabia, as shown in (Figure 1). its climate is desert continental (Dry and hot in summer; cold and rainy in winter). Its temperature ranges between 45° and -3°C, and the average rainfall is 145 mm. storms can happen any time of the year, but they are generally during the spring period.

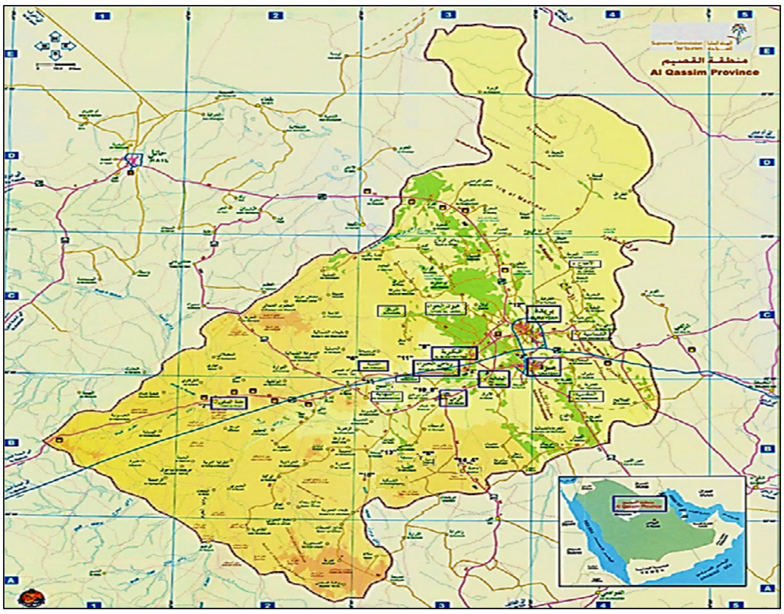

Fig 1. Geologic map of studied locations in Qassim region, KSA

The authors used twenty-three samples from different regions in the Qassim area. They used a pipe housing (60 cm×47square mm) with Teflon–membrane and quartz–fiber filters placed in the middle with a polysynthetic membrane (diameter is 47 mm) and axial extract fan at 1.5 m altitude above ground level, as it is shown in (Figure 2). what stated the location of these samples in (Table 1). Samples were sieved using a 0.125 mm sieve to avoid ash. The Weighted samples were ground and sieved to reach homogeneity. The samples were drying from 105 to 110^{0}C to become completely dry—the weighted samples in polymer Marinelli beaker of 350 cm^3 volume. Marinelli beaker was sealed entirely for more than 30 days to allow radioactive secular equilibrium (Mansour et al., 2017; IAEA, 1989; El-Taher et al., 2003; Abd El-Azeem & Howaida, 2020).

Scintillator detector NaI(Tl) model A320 and SN A3200829 measured gamma lines to assign activity concentrations of different radionuclides. This detector is connected with computer-multichannel analyzer model MCA2500R and serial 25066 (Saleh et al., 2018). The used lead shield (100 mm thick) and copper shield (0.3 mm thick) helped reduce background radiation. The authors calibrated the system and measured the detector's background for 24 hours to accumulate a spectrum. Then what subtracted it from indicated specified photo-peak energy. The Minimum detectable activity was calculated from the background under the same conditions of measurements for ^{226}Ra, ^{232}Th, and ^{40}K and equal 0.09, 0.14, and 0.79 Bq/kg respectively used equation (3) approved by (Chao et al., 2020).

The measured activity concentration (Bq/kg) of individual radionuclides was counted after 24 hours, and the obtained accumulated count using to get the measured activity according to the following equation (Ajibola et al., 2022; Avwiri et al., 2014): -

$$A(Bq/kg) = [(N_s/t_s)- (N_B/T_B)]/[\varepsilon * P * M] \quad (1)$$

Where A(Bq/kg) is the activity of individual radionuclides, (N_s/t_s) is the count per second for sample, (N_B/T_B) is the count per second for background, ε is photopeak efficiency, P is the emission probability, and M is the mass of the sample. The measured activity was reported in (Table 1).

The following equation calculates the radium equivalent (Devi, 2020; UNSCEAR, 2000): -

$$Ra(eq) = C(^{226}Ra) + 1.43\ C(^{232}Th) + 0.077\ C(^{40}K) \quad (2)$$

Where Ra(eq) is radium equivalent activity in (Bq/kg), C(^{226}Ra), C(^{232}Th) and C(^{40}K) is activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in (Bq/kg) respectively.

The measure of minimum detectable activity approved by (Chao et al., 2020) is as the following:

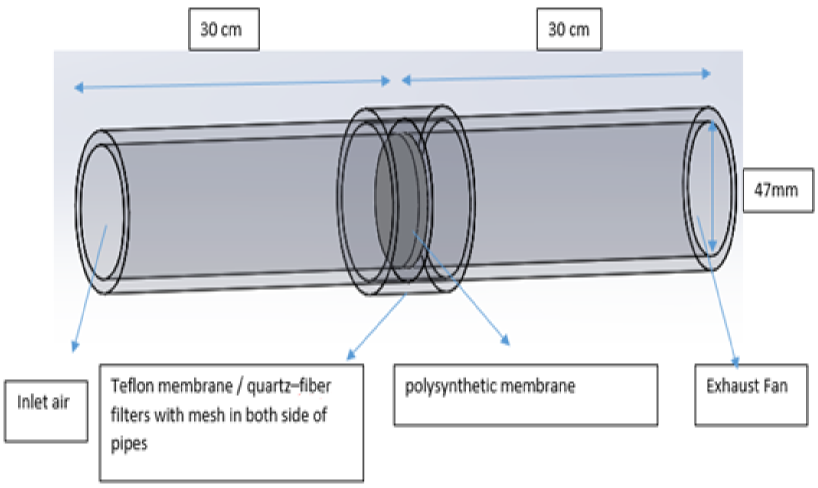

Fig 2. Schematic diagram of collecting PM.

Table 1. Activity magnitude and standard division of Ra-226, Th-232, K-40 (Bq/Kg), radium equivalent, the external and internal hazard index, and level index.

Sample code	Location	Activity (Bq/Kg)			Ra (eq) (Bq/Kg)	Hex	Hin	Iγ
		Ra-226	Th-232	K-40				
S1	Al Rass	28.9±0.05	26.0±0.24	183.9±0.8	80.2	0.22	0.29	0.57
S2	Al Rass	38.9±0.06	34.8±0.35	365.7±1.5	116.8	0.32	0.42	0.85
S3	Al Rass	37.1±0.06	33.3±0.31	317.5±1.3	109.2	0.30	0.40	0.79
S4	Buraidah	40.9±0.06	36.6±0.53	393.8±1.6	123.5	0.33	0.44	0.90
S5	Buraidah	47.6±0.07	44.0±0.57	420.5±1.7	142.9	0.39	0.51	1.04
S6	Buraidah	46.1±0.07	41.4±0.55	408.3±1.7	136.8	0.37	0.49	0.99
S7	Shamasiya	47.3±0.07	42.5±0.70	454.8±1.9	143.1	0.39	0.51	1.04
S8	Al-Rubaiea	43.1±0.07	40.5±0.57	414.7±1.7	133.0	0.36	0.48	0.97
S9	Unaizah	31.9±0.05	27.8±0.22	297.3±1.2	94.6	0.26	0.34	0.69
S10	Unaizah	30.8±0.05	27.3±0.20	256.5±1.0	89.7	0.24	0.33	0.65
S11	Al-Shehiya	44.7±0.07	41.9±0.49	345.6±1.4	131.2	0.35	0.48	0.95
S12	Al-Bakriya	44.1±0.07	41.6±0.59	398.0±1.7	134.2	0.36	0.48	0.97
S13	Al-Melda	41.2±0.06	39.4±0.44	312.5±1.5	121.7	0.33	0.44	0.88
S14	Al Bada'a	31. 0±0.05	28.5±0.36	265.0±1.1	92.1	0.25	0.33	0.67
S15	Al Hilaliya	40.6±0.07	38.0±0.60	373.8±1.6	123.8	0.33	0.44	0.90
S16	Riyadh Al-Khobar	38.1±0.06	34.1±0.61	340.7±1.5	113.1	0.31	0.41	0.82
S17	Al-Khobar	36.4±0.06	36.0±0.41	250.9±1.2	107.2	0.29	0.39	0.77
S18	Al-Fuwailiq	32.0±0.05	33.0±0.31	115.1±0.6	88.0	0.24	0.32	0.62
S19	Aun Al goaa	32.6±0.05	32.7±0.25	135.3±0.6	89.8	0.24	0.33	0.63
S20	Aqla Al soqur	27.0±0.04	26.3±0.22	135.4±0.6	74.9	0.20	0.28	0.53
S21	Al maznab	24.3±0.04	21.2±0.20	278.5±1.1	76.1	0.21	0.27	0.56
S22	Nabhaniyah	10.1±0.03	11.3±0.17	156.2±1.4	38.3	0.10	0.13	0.28
S23	Al Asiyah	11.0±0.03	11.7±0.21	164.7±1.4	40.4	0.11	0.14	0.30
average		35.0±0.06	32.6±0.40	294.99±1.31	104.37	0.28	0.38	0.76
maximum		47.6±0.07	44.0±0.57	454.8±1.9	143.1	0.39	0.51	1.04
minmum		10.1±0.03	11.3±0.17	115.1±0.6	38.3	0.10	0.13	0.28

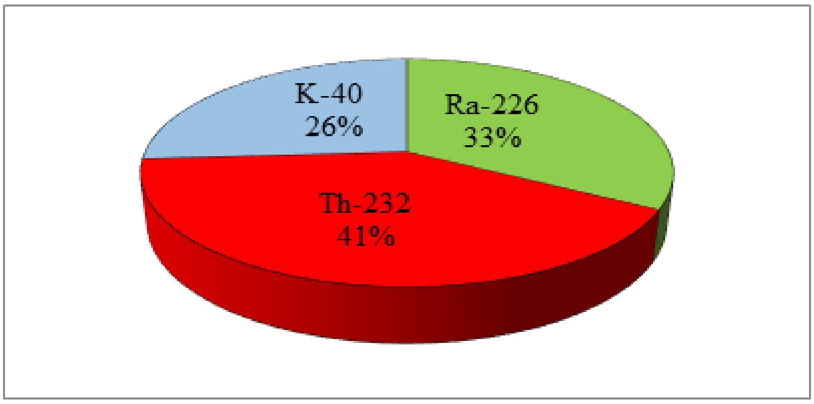

Fig 3. The relative contribution to absorbed dose for ^{226}Ra, ^{232}Th, and ^{40}K

$$MDA(Bq/kg) = (2.71+(4.65*\sqrt{N_B t_m}))/(t_m \varepsilon m) \quad (3)$$

Where N_B is the count per minute for background, tm is the counting time per minute, ε is photopeak detection efficiency for the interested activity per natural radionuclides, and m is the sample weight per volume.

The outdoor absorbed dose rate above 1 meter of the ground level was calculated using equation reported in (UNSCEAR, 2000 & 2008) as the following: -

$$AGDR(nGy/h) = 0.462\, C(^{226}Ra) + 0.604\, C(^{232}Th) + 0.0417\, C(^{40}K) \quad (4)$$

Where $C(^{226}Ra)$, $C(^{232}Th)$, and $C(^{40}K)$ are activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in

Table 2. Environmental hazard index for investigated samples.

Sample code no.	absorbed dose(nGy/h)	Eff Dose (outdoor) mSv/y	Eff Dose (indoor) mSv/y	Annual eff. Dose (μSv/y)	lifetime risk
S1	36.71	0.05	0.18	45.04	3.15
S2	54.23	0.07	0.27	66.54	4.66
S3	50.52	0.06	0.25	61.99	4.34
S4	57.41	0.07	0.28	70.44	4.93
S5	66.09	0.08	0.32	81.09	5.68
S6	63.34	0.08	0.31	77.72	5.44
S7	66.49	0.08	0.33	81.58	5.71
S8	61.68	0.08	0.30	75.68	5.30
S9	43.95	0.05	0.22	53.93	3.77
S10	41.46	0.05	0.20	50.86	3.56
S11	60.34	0.07	0.30	74.04	5.18
S12	62.06	0.08	0.30	76.15	5.33
S13	55.89	0.07	0.27	68.58	4.80
S14	42.54	0.05	0.21	52.20	3.65
S15	57.31	0.07	0.28	70.32	4.92
S16	52.41	0.06	0.26	64.31	4.50
S17	49.04	0.06	0.24	60.18	4.21
S18	39.50	0.05	0.19	48.46	3.39
S19	40.45	0.05	0.20	49.63	3.47
S20	33.97	0.04	0.17	41.67	2.92
S21	35.66	0.04	0.17	43.76	3.06
S22	18.00	0.02	0.09	22.09	1.55
S23	19.02	0.02	0.09	23.34	1.63
average	48.18	0.06	0.24	59.11	4.14
maximum	66.49	0.08	0.33	81.58	5.71
minmum	18.00	0.02	0.09	22.09	1.55

(Bq/kg), respectively, the values 0.462, 0.604, and 0.0417 are obtained from the median values of activity concentration for ^{40}K, ^{226}Ra and ^{232}Th are 400, 35, and 30 Bq/kg, respectively. The measured AGDR(nGy/h) was reported in (Table 2).

RESULTS AND DISCUSSION

The current research determined the natural radionuclides in 23 samples for particulate matters in the Qassim region as shown in (Figure 1), and the results were as the following points:

- The activity concentration (Bq/kg) for Ra-226 fluctuated between 10.1±0.03 to 47.6±0.07, with an average of 35±0.06 Bq/kg. Th-232 fluctuated between 11.3±0.17 to 44±0.57, with an average of 32±0.4 Bq/kg. K-40 fluctuated between 115.1±0.6 to 454.8±1.9, with an average of 294.99±1.31 Bq/kg as is shown in (Table 1) and (Figure 4). The relative contribution equals 26%, 33%, and 41% for ^{40}K, ^{226}Ra, and ^{232}Th, respectively, as shown in (Figure 3).
- The hazard levels of gamma-ray were measured through different calculations such as Radium equivalent, internal and external hazard indexes, absorbed dose, annual effective dose, and lifetime risk, as is listed in (Tables 1, 2) and (Figures 5,6 and 7). The calculated results

of Ra(eq) (Bq/kg) fluctuated between 38.3 to 143.1 with an average of 104.37 used equation approved by (El Taher et al., 2014; Mansour et al., 2017; Khandaker et al., 2020), So the obtained is lower than the global values approved by (NEA, 1979).

• The external and internal hazards were calculated according to the equation approved by (Tufail et al., 2005; Joel et al., 2018). As mentioned in (Table 1) and plotted in (Figure 5), It is clear that (Hex) fluctuated between 0.10 to 0.39 with an average of 0.28 Bq/kg, and (Hin) fluctuated between 0.13 to 0.51 with an average of 0.38 Bq/kg. These results were within the safe limits and less than unity.

• The represented level index (Iγ) was calculated using the equation approved by (El Taher et al., 2014). It is clear that the lower value of (Iγ) is 0.28, and the upper value is 1.04 with a mean of 0.76, which is also presented in (Table 1) and (Figure 5). This magnitude closes to unity.

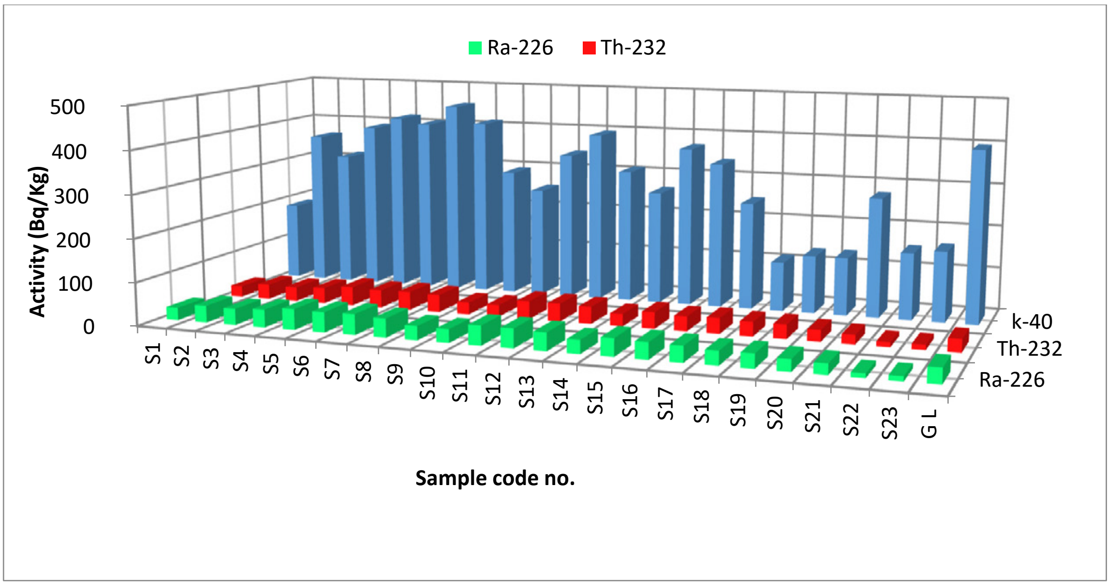

Fig 4. Activity concentration (Bq/kg) for ^{226}Ra, ^{232}Th and ^{40}K for whole samples from different locations of Al Qassim, Saudi Arabia comparison with global limits

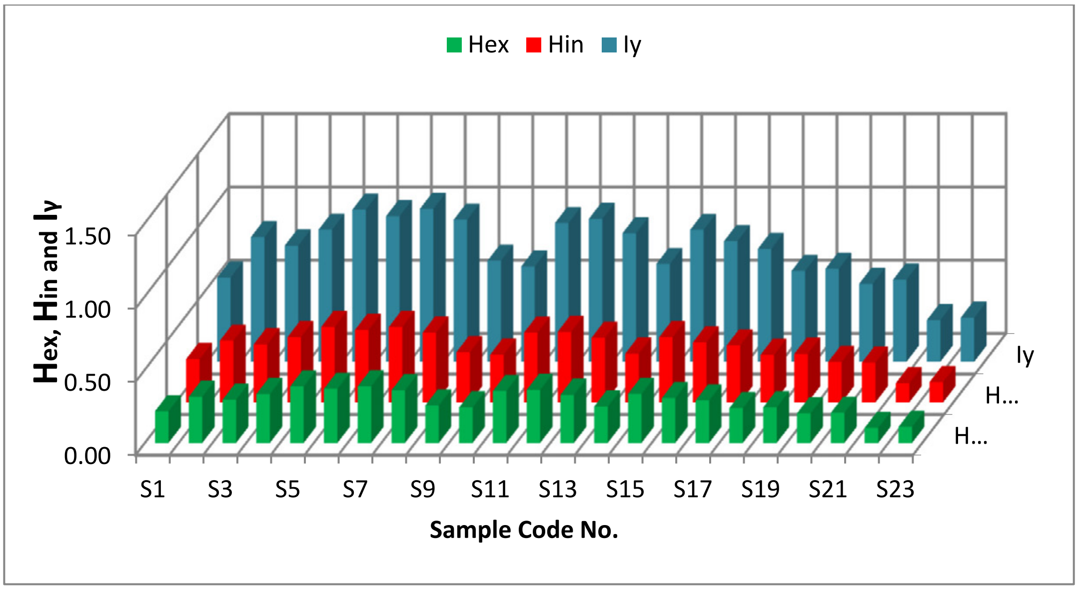

Fig 5. Represent the external and internal hazards in addition to gamma level index for investigated 23 samples

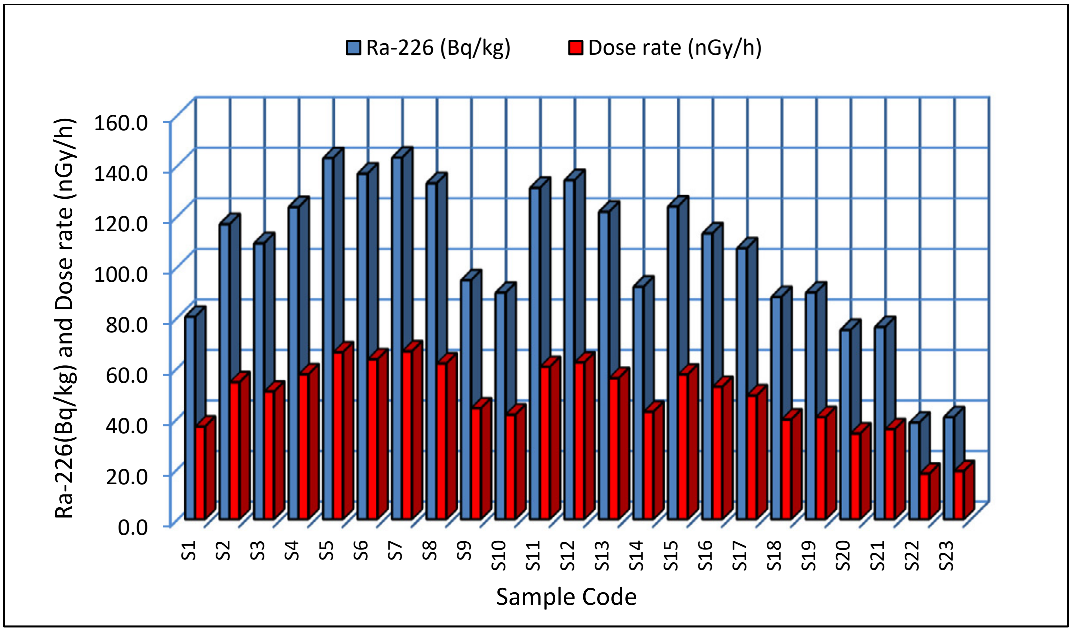

Fig 6. Represent Radium equivalent (Bq/kg) against dose rate (nGy/h).

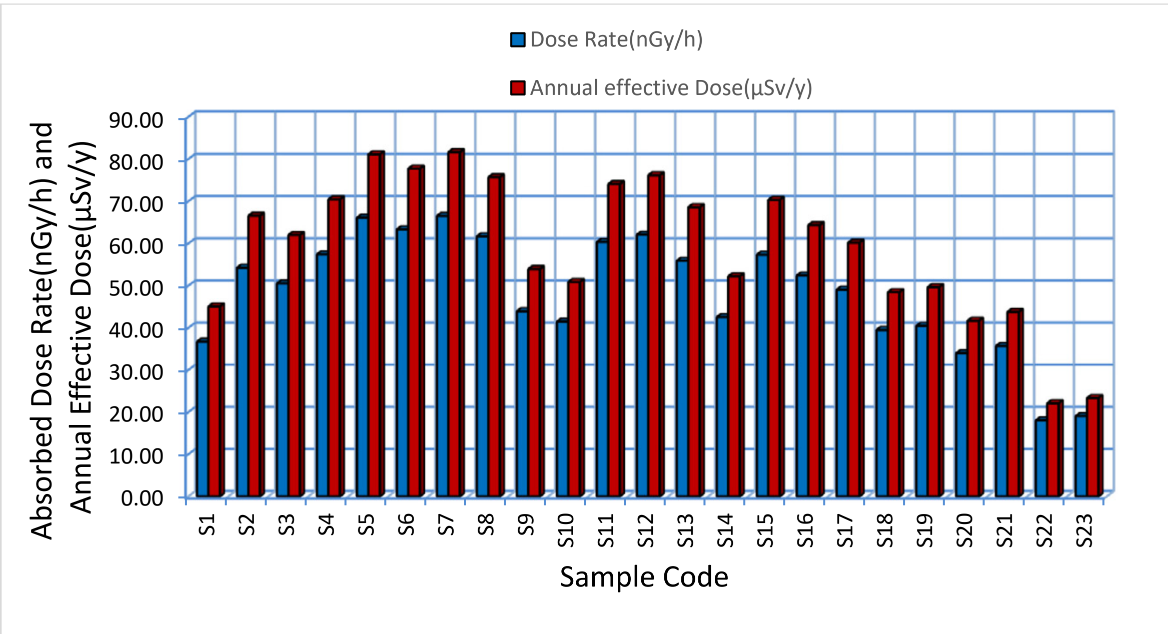

Fig 7. Represent the relation between dose rate (nGy/h) and annual effective dose (µSv/y)

- Table 2 and (Figures 6 and 7) represent the calculated environmental radiation hazard index (absorbed dose, Radium equivalent, annual effective dose, and lifetime risk). All of these variables shew the health risks that affect human beings. The current research used the equation mentioned by (Mansour et al., 2017) to calculate these variables. The absorbed dose (nGy/h) fluctuated between 18 to 66.49, with an average of 48.18 nGy/h, which are compatible with reported public limits (ICRP, 1993).
- Effective dose per year (mSv/y) for outdoor radiation fluctuated between 0.02 to 0.08 with

an arithmetic mean of 0.06 mSv/y. Indoor radiation fluctuated between 0.09 to 0.33 with an arithmetic mean of 0.24 mSv/y. The annual effective dose fluctuated between 22.09 to 81.58 µSv/y with an arithmetic mean of 59.11µSv/y. Lifetime risk ranges from 1.55 to 5.71, with an arithmetic mean of 4.14. All of these results are suitable for public limits.

- (Table 3) represented distribution correlation between radionuclides activity ($^{226}Ra/^{232}Th$, $^{226}Ra/^{40}K$, and $^{232}Th/^{40}K$). It clarifies the relationship between the daughters of the series. The relation between Ra-226 and Th-232 is close to unity with R-squared value 0.9759 (Figure 8), so the authors deduced that they are analogical distribution. The distribution between ($^{226}Ra/^{40}K$ and $^{232}Th/^{40}K$) is nearly normal distribution according to public values (ICRP, 1991; UNSCEAR, 2000). The $^{226}Ra/^{40}K$ ratio fluctuated between 0.06 to 0.28 with a mean of 0.13. The rate of $^{232}Th/^{40}K$ fluctuated between 0.07 to 0.27 with a standard of 0.12, with R-squared values 0.6302 and 0.5272, respectively, as shown in (Figures 9 and 10). These ratios are nearly normal

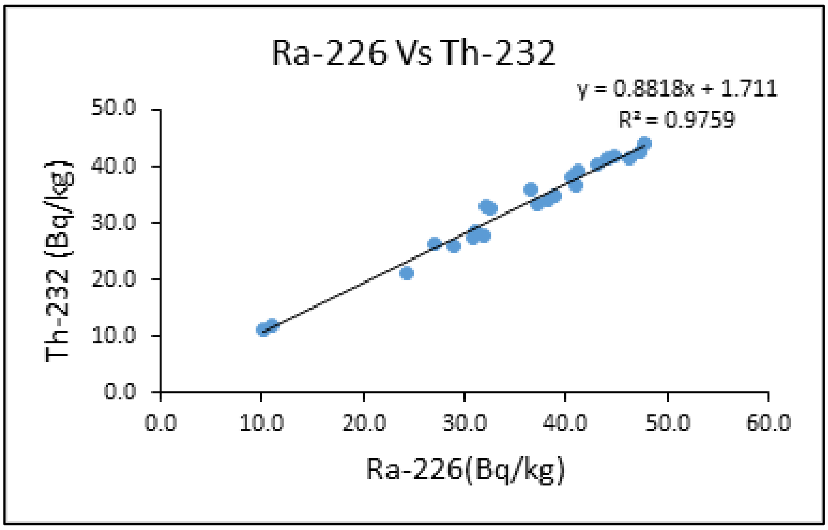

Fig 8. Represent the correlation between Ra-226 and Th-232 (Bq/kg)

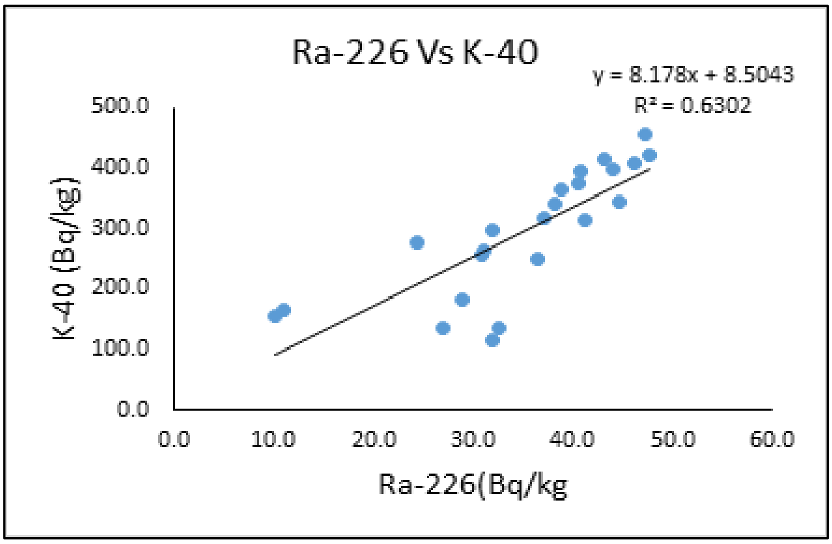

Fig 9. Represent the correlation between Ra-226 and K-40 (Bq/kg)

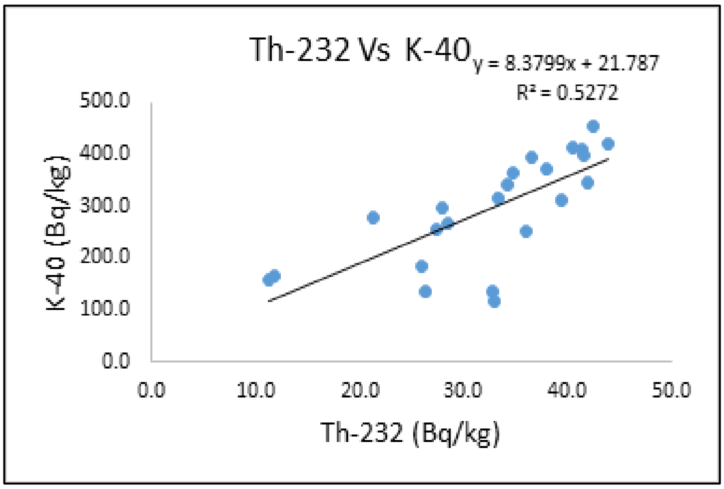

Fig 10. Represent the correlation between Th-232 and K-40 (Bq/kg)

Table 3. Distribution correlation between radionuclides.

Sample code	$^{226}Ra/^{232}Th$	$^{226}Ra/^{40}K$	$^{232}Th/^{40}K$
S1	1.11	0.16	0.14
S2	1.12	0.11	0.10
S3	1.11	0.12	0.10
S4	1.12	0.10	0.09
S5	1.08	0.11	0.10
S6	1.11	0.11	0.10
S7	1.11	0.10	0.09
S8	1.06	0.10	0.10
S9	1.15	0.11	0.09
S10	1.13	0.12	0.11
S11	1.07	0.13	0.12
S12	1.06	0.11	0.10
S13	1.05	0.13	0.13
S14	1.09	0.12	0.11
S15	1.07	0.11	0.10
S16	1.12	0.11	0.10
S17	1.01	0.15	0.14
S18	0.97	0.28	0.29
S19	1.00	0.24	0.24
S20	1.03	0.20	0.19
S21	1.15	0.09	0.08
S22	0.90	0.06	0.07
S23	0.94	0.07	0.07
average	1.07	0.13	0.12
maximum	1.15	0.28	0.29
minimum	0.90	0.06	0.07

Table 4. Comparison values of activity concentration of natural radionuclides with reported from different countries of the world.

Country	Activity concentration (Bqkg^{-1})				reference
	Ra-226	U-238	Th-232	K-40	
Saudi Arabia (Qassim)	10.1-47.6 (35)	---	11.3-44.0 (32.6)	115.1-454.8 (294.99)	Present study
South Africa	(53.59)	(12.20)	(6.62)	(278.51)	Violet et al,2018
Peninsula	8-16.5 (13.5)	6.2-9 (7.8)	6.4-12.7 (8.7)	123.4-220 (183)	Zaid et al, 2017
Baghdad	13-19 (16.2)	---	9-14 (11.9)	200-240 (218.3)	Ali et al, 2019

distribution according to the same reason above.

• The relative contribution of activity concentration was presented in (Figure 3) and equal 26%, 33%, and 41% for ^{40}K, ^{226}Ra, and ^{232}Th, respectively.

• Table 4 compares the results obtained in the present study for ranges and average of activity concentration of natural radionuclides with reported from different countries. It is clear that the results are higher than another country for Th-232 and K-40, but it does not cause risk for human health because it is in line with the global reported by UNSCEAR 2000 and 2008. The global values for ^{226}Ra, ^{232}Th, and ^{40}K are 35, 30, and 400 Bq Kg^{-1} respectively.

CONCLUSION

The study of radioactive measurements for particulate matter is significant because of its effect on human wealth. The global institutions of radiation protection recommended studying pollution due to terrestrial sources, especially particulate matter because it is easy to affect human health through breathing. The current research measured the activity concentration for ^{226}Ra, ^{232}Th, and ^{40}K of 23 particulate matter samples collected from a different place from Qassim, Saudi Arabia. The obtained results of radiation hazard risks were within the same limits of the global report's safety criteria. Therefore, the investigated locations were safe for human health. And the normal distribution of radionuclides. The relative contribution equals 26%, 33%, and 41% for ^{40}K, ^{226}Ra, and ^{232}Th, respectively. The obtained data help the investigators follow the future pollution exchange due to Scientific progress in using radioactive materials.

GRANT SUPPORT DETAILS

The present research did not receive any financial support

CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research

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