Natural Radioactivity Measurements for Assessment Radiation Hazards from Surface Soil of Industrial Yanbu City, Saudi Arabia

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Abstract: The present study was carried out to determine the activity concentrations of 40K, 226Ra and 232Th in surface soil samples collected from twenty five different locations of Industrial Yanbu city located in western region of Saudi Arabia, using a NaI(Tl) gamma-ray spectrometer. The activity concentrations of 226Ra, 232Th and 40K in the soil samples from the studied area ranged from 25.21 Bq kg^{-1} to 50.73 Bq kg^{-1}, 25.74 Bq kg^{-1} to 65.11 Bq kg^{-1} and 109.82 Bq kg^{-1} to 987.09 Bq kg^{-1} with overall mean values of 40.65, 42.89 and 513.16 Bq kg^{-1} respectively. The mean radium equivalent (Raeq) and outdoor radiation hazard index (Hex) for the area under study were determined as 140.8 Bq kg^{-1} and 0.65 respectively. The absorbed dose rate due to three primordial radionuclides lies in the range from 34.55 to 97.47 $nGyh^{-1}$ with a mean of 65.8 $nGyh^{-1}$, which yields the annual effective dose of 0.81 $mSvy^{-1}$ which is well below the permissible limit. The excess lifetime CR ranged from (1.54 to 4.39) $\times10^{-4}$, with an arithmetic mean of 2.96×10^{-4}, which is in accordance with the global average.The measured values are comparable with other global radioactivity measurements and are found to be save for public and environment. This study would be useful for establishing base line data on the gamma background radiation levels in the study areas for assessment of radiation exposures to the population.

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Key words: Gamma Spectrometry, Annual effective dose, External hazard index.

1. Introduction

The main natural contributors to external exposure from gamma rays are 238U, 232Th and 40K. These radionuclides are widely spread in the earth's environment and it is present at trace levels in all ground formations. Beck suggested that 50–80% of the total gamma flux at the earth's surface arises from 40K and 232Th, 238U series (IAEA,1996). It is therefore important to determine what these sources are and their individual contributions to the total radiation dose. Estimates of total radiation dose to the world population have shown that about 96% is from natural sources while 4% is from artificial sources (Chougankar *et al.,* 2003). Soil is an important environmental material used, e.g., for building raw materials and products, for streets and playgrounds, and for land filling. Therefore, knowledge of the concentrations of natural radionuclides in soils is essential for an accurate assessment of possible radiological risks to human health in this region and essential in the sense of controlling radiation levels. In the control of radiation hazards, it is necessary to know the rate at which radiation is received so the estimates of the measured radionuclide content have been made for calculating the absorbed dose rate of gamma radiation and the radium equivalent (Req) and the external hazard index (Hex), which resulted from the natural radionuclides in soil. Radioactivity in soil has been studied in many regions of the world (see e.g. Jankovic Mandic´ and Dragovic, 2010; Abd El-mageed *et al.,* 2011; Ridvan *et al.,* 2011; Kolo, *et al.,* 2012; Nrsama Heru Apriantoro; 2013, Saleh and Abu sayhab, 2014) to obtain data on natural radioactivity, which can be used to establish if and where local controls are needed. Such data also enrich the global data bank on radioactivity that will allow a more accurate estimation of global average values of dosimetric quantities. In Saudi Arabia there is a few surveys of radioactivity in soils have been carried for different regions(Al-Aamer., 2008; Al-Zahrani., 2012; El-Taher & al-zahrani 2014).There is no baselines of concentration of natural and anthropogenic radioisotopes have been reported. Therefore, the main subject of present study is to determine the levels of 226Ra,232Th and 40K activity concentrations and the associated external gamma dose rate estimations in soil samples taken at the surface from different locations in the Industrial Yanbu city, Saudi Arabia. The outcomes of this work will form a baseline data set, which will enable estimations of population exposure. The data will also contribute to the radioactivity mapping of Saudi Arabia surface soils levels.

2. Location of Study Area

Industrial Yanbu city is located geologically, on the Red sea in the western region of Saudi Arabia, 350 kilometers Northwest of Jeddah city. It is situated between the latitude of 38.2275N and longitudes of 23.999444E, within area 185km^2. This area is industrial region as there are large industrial companies such as for petroleum and chemical factories.This feature make this region an interesting candidate for radiological studies, although, there is no a study on environmental doses from external exposures before. Therefore, the main objective of present study is to determine the natural radioactivity and the annual effective dose from external exposure for this area. The geological map of the study area in Fig 1.

Fig(1). Location map of Industrial Yanbu city.

3. Materials and Methods

3.1 Sample collection and analysis

Twenty five surface soil (about 0–5 cm) samples were collected from randomly selected locations in Industrial Yanbu city located in the western region of Saudi Arabia. Soil samples were dug up to a depth of about 5 cm at each corner of the identified 1 m^2 area and at its center. The five soil samples obtained were then mixed together to obtain the soil sample representing that city of land, the extraneous material such as plant roots, stones were removed from the mixture. Soil samples were dried in an oven at 100 °C for 24 hours, (Veiga *et al.,* 2006), and then crushed, ground to fine powder and homogenized by mixing before the gamma spectrometric analysis.Then a composite sample of about 400 g were sealed and kept for about 4 week's period to allow radioactive equilibrium among the daughter products of radon (222Rn), thorn (220Rn) and their short lived decay products (Mollah *et al.,*1987).The activity concentrations of 226Ra,232Th and 40K for all homogenized and equilibrium samples were measured by a gamma ray spectrometry using ″3x3″ NaI (Tl) with a 1024 microcomputer multichannel analyzer. The detector has a peak gamma ray efficiency of 2.3×10^{-2} at 1332 keV Co-60 and an energy resolution (FWHM) of 7.5 % at 662 keV and operation bias voltage 805V dc. The detector was housed inside a massive cylindrical lead shield to reduce the background radiation. The specific activity of ^{226}Ra was evaluated from gamma-ray lines of ^{214}Bi at 609.3, 1120.3 keV and ^{214}Pb at 351 keV,while the specific activity of ^{232}Th was evaluated from gamma-ray lines of ^{228}Ac at 338.4, 911.1 and 968.9 keV, ^{40}K was determined by measuring its single peak at 1460.8 keV. Activity calculations have been carried out using the procedure given by (Lalit and Ramachandra, 1980), the activity concentrations in each sample were evaluated using the following equation Abbady., 2004; El-Taher & al-zahrani 2014:-

$$Ac\,(\text{Bq kg}^{-1}) = Nc / \varepsilon\, \beta\, M \text{ ………. (1)}$$

where Nc is the net gamma counting rate (counts per second), ε the detector efficiency of the specific γ–ray, β the absolute transition probability of Gamma–decay and M the mass of the sample (kg).

3.2. Assessment of radiation Hazard indices from the soil.

To assess the real activity level of ^{226}Ra, ^{232}Th and ^{40}K in soil,a common radiological index has been defined in terms of radium equivalent activity (Ra_{eq}) in Bq kg^{-1} can be used, provides a very useful guideline in regulating the safety standards in radiation protection for a human population. The index was calculated through the following relation (Beretka and Mathew, 1985):

$$Ra_{eq}\ (\text{Bqkg}^{-1}) = C_{Ra} + 1.429C_{Th} + 0.077C_K \text{ ………. (2)}$$

The formula is based on the assumption that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 481 Bq kg^{-1}of ^{40}K produce the same gamma-ray dose rate (Stranden, 1976).Avalue of 370Bqkg^{-1} coresponds to 1 mSv y^{-1}.

To limit the annual external gamma-ray dose to 1.5mSvy^{-1} for the samples under investigation, the external hazard index is given by the following equation(Beretka and Mathew, 1985):

$$H_{ex} = C_{Ra}/370 \text{ Bq kg}^{-1} + C_{Th}/259 \text{ Bq kg}^{-1} + C_K/4810 \text{ Bq kg}^{-1} \text{ …….(3)}$$

where C_K,C_{Ra} and C_{Th} are the activity concentrations (Bq kg^{-1}) of the specific radiation.The maximum value of H_{ex} to be less than unity corresponds to the upper limit of Ra_{eq} (370Bqkg^{-1}).

The absorbed gamma dose rates D (nGyh^{-1}) in air at 1m above the ground surface for the uniform distribution of radionuclides were calculated based on guidelines provided by UNSCEAR, 2000:

D (nag h^{-1}) = $0.427C_{Ra} + 0.623C_{Th} + 0.043C_K$ …………………… (4)

where C_K, C_{Ra} and C_{Th} are the activity concentrations (Bq kg^{-1})of ^{40}K, ^{226}Ra and ^{232}Th, respectively, in the samples.The annual effective dose equivalent (AEDoutdoor) was calculated from the absorbed dose by applying the dose conversion factor of 0.7 Sv Gy^{-1} with an outdoor occupancy factor of 0.2 (UNSCEAR,2000):

AEDoutdoor (mSvy^{-1}) = D (nGyh^{-1}) ×8,766 hy^{-1} × 0.7(SvGy^{-1})× 0.2 ×10^{-6} ………. (5)

where 8,766 hy^{-1} is the number of hours in 1 year. 10^{-6} is conversion factor of nano and milli.

3.3Excess lifetime cancer risk outdoors

Excess lifetime cancer risk outdoors (CR) was calculated as follows (Antovic *et al.,* 2012; El-Taher and Al-zahrani, 2014):

CR = AEDoutdoor × T× RF ……. (6)

where AEDoutdoor is annual outdoor effective dose (mSv), RF is the risk factor (Sv^{-1}), fatal CR per sievert. for detriment-adjusted cancer risk of 5.52 × 10^{-2} Sv^{-1} for the whole population (UNSCEAR, 2000) and T the lifetime (70 y).

4. Results and Discussions

4.1 Activity concentration

The activity concentrations of radionuclides 226Ra, 232Th, and 40K in soil samples collected from 25 locations of Industrial Yanbou city in Saudi Arabia are given in Table 1.The range of activity concentrations of 226Ra ranged from 25.21±4.38 Bq kg^{-1} (S11) to 50.73±4.38 Bq kg^{-1} (S21) with an average value of 40.65 Bq $kg^{-1,}$ for 232Th varies from 25.74 ±3.13 (S15) to 65.11±7.92Bq kg^{-1} (S17) an average value of 42.89 Bq kg^{-1} and for 40K varies from 109.82±9.44 Bq kg^{-1} (S1) to 987.09±8.49Bq kg^{-1} (S20) an average value of 513.16 Bq kg^{-1}, this average value was found to be higher than that averages of both 226Ra and 232Th. Also, 40K is the most abundant, about 86% of the total (226Ra + 232Th + 40K) which is in agreement with the well-known fact that potassium in the earth's crust is of the order of percentage while U and Th are in ppm level (Ramasamy *et al.,* 2011). The variation in the specific activities from sample to sample is due to the difference in their locations in the city.

The world range and average radioactivity concentrations of 238U, 232Th and 40K in soil have been reported in UNSCEAR, 2000 as 30 (10–50), 45 (16– 110) and 420 (140–850) Bq.kg^{-1} respectively. Table(1) shows that the average values of 226Ra and 40K activity concentrations reported for the study area are higher than world average 30 Bq/kg and 420 Bqkg^{-1} for 226Ra and 40K, where as the activity concentration of 232Th is lower the world average value 45 Bq/kg, whereas, the range of activity concentrations in the study area for 238U-series, 232Th-series and 40K are within the world range for soils as reported in UNSCEAR2000. The average activity concentrations of 232U, 232Th and 40K in different of soil samples under study are given in Figure 2.

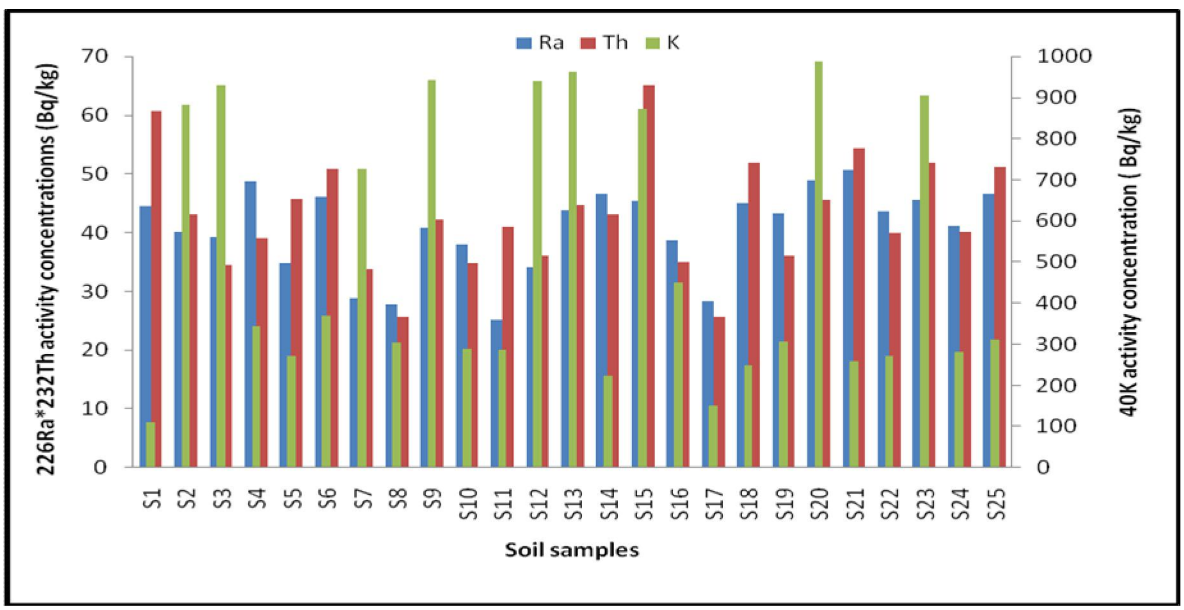

Fig.2 Activity concentrations of 226Ra, 232Th and 40K for surface soil samples collected from different locations of the Industrial Yanbu city, Saudi Arabia

Table (1).The values ^{226}Ra,^{232}Th and ^{40}K activity concentrations,radium equivalent activity (Ra_{eq}) and External hazard index(H_{ex}) in the soil samples of the Industrial Yanbu city, Saudi Arabia.

Sample location	Radioactivity concentration($Bqkg^{-1}$)			Ra_{eq} (Bq/kg)	External hazard index (H_{ex})
	^{26}Ra	^{232}Th	^{40}K		
S1	44.525±3.42	60.79±9.44	109.82±9.44	139.85	0.73
S2	40.055±3.08	43.04±5.23	883.45±759	169.58	0.73
S3	39.26±3.02	34.42±4.19	930.46±8.00	160.09	0.67
S4	48.71±4.19	38.98±4.74	345.48±2.79	131.01	0.64
S5	34.85±3.01	45.69±5.55	272.52±2.34	121.12	0.59
S6	46.14±3.98	50.86±6.18	370.26±3.18	147.32	0.72
S7	28.79±2.23	33.85±6.77	726.33±6.24	133.09	0.57
S8	27.84±2.39	25.74±4.43	303.38±2.60	87.98	0.41
S9	40.88±3.15	42.17±5.13	941.98±8.10	173.67	0.74
S10	37.955±3.78	34.91±4.24	288.25±2.47	110.04	0.53
S11	25.21±2.18	41.06±4.99	285.41±2.45	105.85	0.51
S12	34.09±2.65	36.06±4.38	939.21±8.07	157.94	0.66
S13	43.79±3.34	44.71±5.43	964.08±8.26	181.92	0.78
S14	46.645±4.01	43.13±5.28	224.69±1.94	125.57	0.63
S15	45.48±3.51	65.11±7.92	871.91±7.50	205.65	0.93
S16	38.73±3.38	35.06±4.38	449.39±3.86	123.42	0.57
S17	28.30±2.43	25.74±3.13	149.57±1.28	76.59	0.38
S18	44.97±3.88	51.84±6.31	248.74±2.13	138.19	0.69
S19	43.36±3.74	36.09±6.61	307.07±2.64	118.58	0.58
S20	48.97±3.77	45.53±5.54	987.09±8.49	190.04	0.82
S21	50.73±4.38	54.35±6.61	259.47±2.23	148.38	0.75
S22	43.65±4.39	40.01±6.88	270.76±2.32	121.66	0.60
S23	45.64±3.51	51.905±4.87	906.13±7.79	189.58	0.84
S24	41.12±3.53	40.04±4.87	280.33±2.41	119.91	0.58
S25	46.64±4.02	51.29±6.24	312.49±2.68	143.99	0.65
Min.-Max	25.21-50.73	25.74- 65.11	109.82 - 987.09	76.59- 205.65	0.38 – 0.93
Mean	40.65	42.89	513.16	140.8	0.65
World (UNSCEAR 2000)	32 (10- 50)	45 (16- 110)	420 (140-850)	370	< 1

The results for natural radionuclides 226Ra, 232Th and 40K in soil samples in this work have been compared with the results for different countries of the world as shown in Table 2. When the present results were compared with the other areas of Saudi Arabia soil, the average value of 226Ra, 232Th were found in the present work was somewhat higher than reported for Riyadh, Albaha and Al Qassim, but 40K was found slightly lower than the result of Al Qassim soil. The comparison of ^{40}K activity concentration of the present study with the other countries shows that the average value of this radionuclide in the present soil was higher than the reported of Malaysia, Nigeria, Jordan and was smaller than Yemen. The average value of 226Ra in the present study was found higher than the reported for Nigeria, but it was lower than reported for Malaysia and Jordan, it was found nearly the same as reported for Yemen. Finally, the average value of 232Th in the present study was found lower than the reported average values for the soil of Yemen and Malaysia but it was found higher than the other countries listed in Table 2. The variations in the concentrations of the radioactivity in the soil of the various locations of the world, depend upon the geological and geographical conditions of the area and the extent of fertilizer applied to the agriculture lands UNSCEAR., 2000.

4.2 Radiation hazards

The results for the radium equivalent activity and the external indices of the present work are presented in Table 1.The Ra_{eq} values varying from 76.59 (s.no.17) to 205.65 (s. no.15)Bq $kg^{-1}$with a mean value of 140.8 $Bqkg^{-1}$.These values are lower than the permissible maximum value of 370 Bq kg^{-1} (UNSCEAR 1993; NEA-OECD 1979).

The calculated external hazard values for soil samples varies from 0.38(s.no.17) to 0.93(s.no.15) with a mean value of 0.65. All the soil samples have values lower than unity. Therefore, based on these results of radium equivalent activity and external hazard indices, one can conclude that there is no health hazard from the soil of Industrial Yanbu city and no radiation hazard attributed to the radiation from the three radionuclides will be faced by peoples living in or visiting this region.

Table(2).Comparison of natural radioactivity concentration ($Bqkg^{-1}$) in the soil samples for present study with previous study reported from different countries of the world.

Country	Mean and range activity concentration ($Bqkg^{-1}$)			References
	^{226}Ra	^{232}Th	^{40}K	
Industrial Yanbu city Saudi Arabia	40.65 (50.41 - 101.46)	42.89 (51.47-130.21)	513.16 (109.82 - 987.09)	Present study
AlQasseem, Saudi Arabia	9.3 (1.4 -35.3)	12.3 (2.5 - 39)	535 (212- 915)	El-Taher & al-zahrani 2014
Riyadh, Saudi Arabia	14.5 (11 -30)	11(7 - 25)	225 (89- 320)	Al-Aamer., 2008
Albaha, Saudi Arabia	37 (30 -45)	32(26 - 37)	343 (263- 435)	Al-Zahrani., 2012
Yemen	44 (16.6 -84.4)	58(18-113)	823(64 -1667)	Abd El-mageed *et al.,* 2011
Malaysia	127 (7-55)	304(23-1806)	302(6-2522)	Nrsama Heru Apriantoro;2013
Nigeria	7.8 (1 -26.5)	29.4 (2.2 -70)	229 (43 - 468)	Kolo, *et al.,* 2012
Turkey	21.0(13–31)	23.5(14–34)	363.5(204–572)	Ridvan et al;2011
Jordan	57.7(47.3-77.8)	18.1(14-20.8)	138.1(31.3-251.5)	Saleh and Abu shayheb; 2014
World average	32 (16-110)	45 (11-64)	420 (140-850)	UNSCEAR., 2000

Table 3, gives the estimated external gamma dose rate, annual effected dose and Excess lifetime cancer risk outdoors due to natural gamma emitters as measured in soil under study. From this table we can indicate the following:-

1 - The calculated total absorbed dose and annual effective dose rates of samples are tabulated in Table(3). It is observed that the absorbed dose rate calculated from activity concentration of ^{226}Ra ranged between 10.76 (s.no.11)to 21.66 (s.no.21), for ^{232}Th ranged from 16.03 (s.no.17) to 40.56(s.no.15) and finally ^{40}K ranged from 4.72 (s.no.17) to 42.44 (s.no.20) $nGyh^{-1}$ with a mean values of 17.36, 26.72 and 21.72 respectively. Median value of the absorbed dose rates in air from radionuclides of the 238U series has been globally found to be 16 $nGyh^{-1}$, with population weighted value of 15 $nGyh^{-1}$, as from radionuclides of the 232Th series 18 $nGyh^{-1}$, with population weighted value 27 $nGyh^{-1}$(UNSCEAR 2000).The total absorbed dose from the three terrestrial gamma radiation as present in Table (2) ranged from 34.55 $nGyh^{-1}$ (s.no.17) to 97.47 $nGyh^{-1}$(s.no.15) with an average value of 65.8 $nGyh^{-1}$, which is slightly higher than the population weighted average value of global primordial radiation of 59 $nGy\ h^{-1}$ (UNSCEAR 2000), close to the average value of natural gamma radiation dose rate of China (62.0 $nGyh^{-1}$) (UNSCEAR 2000) and in the average value range of world (UNSCEAR 2000). Fig 3 shows the absorbed dose and radium equivalent of the present soil samples.

The contribution to total external dose rate of Th and U series and 40K was calculated as 41%, 26%, and 33%, respectively, as shown in Fig 4. Concerning world average contribution value determined by UNSCEAR (36%, 32%, 32%, respectively).

2 - The annual effective dose rates from outdoor terrestrial gamma radiation were estimated and presented in Table (2). They varied from 0.042 to 0.111 mSv $year^{-1}$ with an average value of 0.081 mSv y^{-1}, which is close to the worldwide average (0.07 mSv y^{-1}) for outdoors annual effective dose (UNSCEAR 2000) and is about 8.1% of the 1.0 mSv $year^{-1}$ recommended by the International Commission on Radiological Protection (ICRP-65 1993) as the maximum annual dose to members of the public. Therefore, the study area is still in the zones of normal radiation level, which leaves the soil radioactivity there less a threat to the environment as well as the human health.

3 - The values of Excess lifetime cancer risk outdoor (CR) for different locations in industrial Yanbu city ranged from 1.54 $\times10^{-4}$ to 4.39 $\times10^{-4}$ with a mean 2.96 $\times10^{-4}$ (Table 3). The present average is comparable to the world average ($2.9x10^{-4}$) UNSCEAR, 2000. The results obtained in this study fall within the range of values reported in similar studies conducted worldwide and are below the values, which can cause the significant radiation hazard.

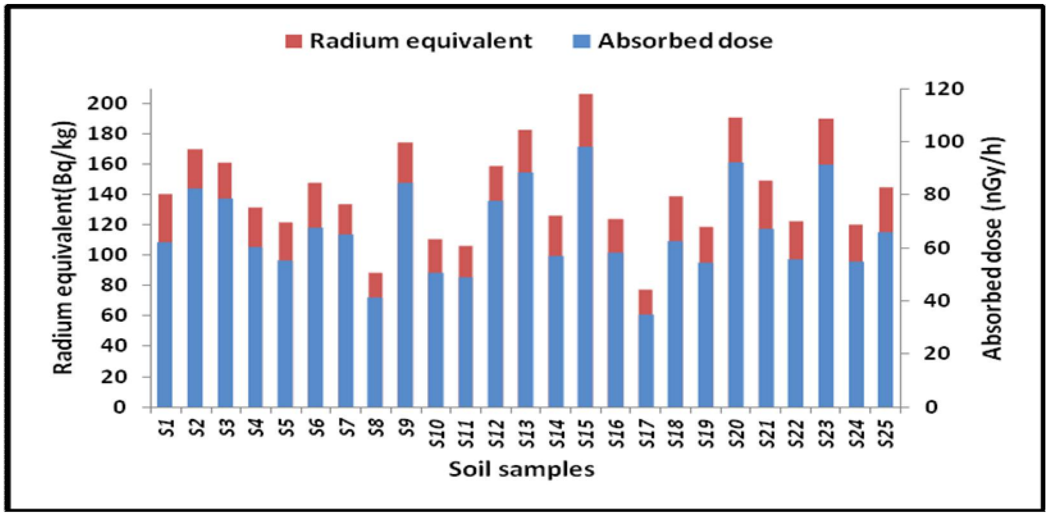

Fig.3 Absorbed dose rate (nGy/h) Radium equivalent (Bq/Kg) for soil samples from different locations in Industrial Yanbu city, Saudi Arabia.

Table(3). Air- absorbed dose rates, annual effective doses and Excess lifetime cancer risk calculated for surface soil samples collected from the Industrial Yanbu city, Saudi Arabia

Sampels no.	Absorbed dose (nGh^{-1})				AEDoutdoor (mSv/y)	Excess lifetime cancer risk outdoors (CR) $\times 10^{-4}$
	^{226}Ra	^{232}Th	^{40}K	Total(D)		
S1	19.01	37.87	4.72	61.61	0.076	2.78
S2	17.10	26.81	37.99	81.90	0.101	3.70
S3	16.76	21.44	40.01	78.21	0.096	3.51
S4	20.80	24.28	14.86	59.94	0.074	2.71
S5	14.88	28.46	11.72	55.06	0.068	2.49
S6	19.70	31.69	15.92	67.31	0.083	3.04
S7	12.30	21.09	31.23	64.61	0.079	2.89
S8	11.89	16.04	13.05	40.70	0.050	1.83
S9	17.46	26.27	40.51	84.23	0.103	3.77
S10	16.21	21.75	12.39	50.35	0.062	2.27
S11	10.76	25.58	12.27	48.61	0.060	2.20
S12	14.56	22.46	40.39	77.41	0.095	3.48
S13	18.69	27.85	41.46	88.01	0.108	3.95
S14	19.92	26.87	9.66	56.45	0.069	2.53
S15	19.42	40.56	37.49	97.47	0.120	4.39
S16	16.54	21.84	19.32	57.70	0.071	2.60
S17	12.08	16.03	6.43	34.55	0.042	1.54
S18	19.20	32.29	10.70	62.19	0.076	2.78
S19	18.51	22.49	13.20	54.20	0.067	2.45
S20	20.91	28.37	42.45	91.72	0.113	4.14
S21	21.66	33.86	11.16	66.68	0.082	3.00
S22	18.63	24.92	11.64	55.20	0.068	2.49
S23	19.48	32.34	38.96	90.79	0.111	4.06
S24	17.56	24.94	12.05	54.55	0.067	2.45
S25	19.91	31.95	13.44	65.30	0.080	2.93
Rang	10.76-21.66	16.03-40.56	4.72-42.45	34.55-97.47	0.042- 0.111	(1.54 - 4.39)
Mean	17.36	26.72	21.72	65.8	0.081	2.96
World average (UNSCEAR 2000)				59	0.07	2.9

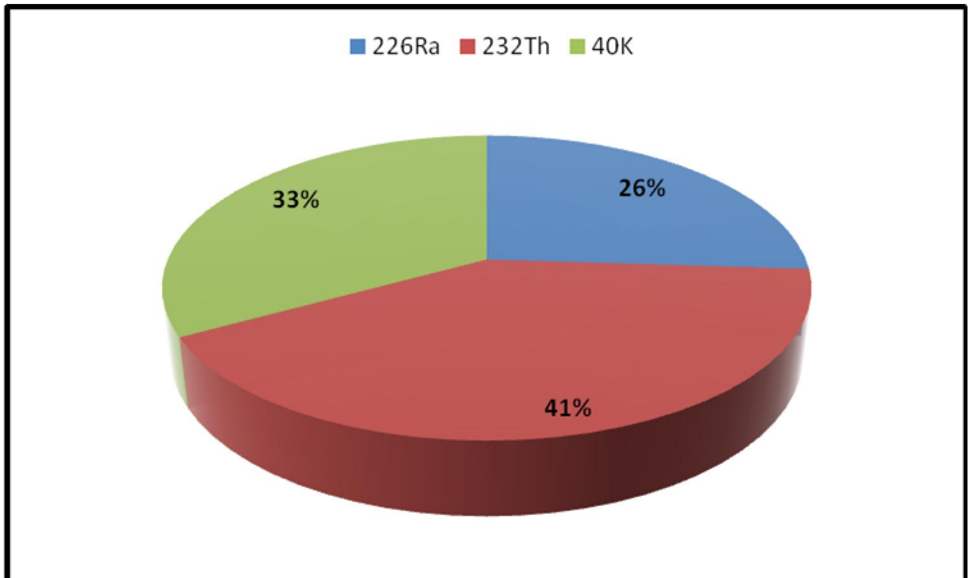

Fig. 4 Percentage contribution to the total absorbed dose of ^{226}Ra, ^{232}Th and ^{40}K

Conclusion

The results obtained in this work shows that:-

1- The mean activity concentrations for ^{226}Ra and^{232}Th and ^{40}K are Bqkg^{-1}, 40.65 Bqkg$^{-1,}$ 42.89 and 513.16 Bqkg^{-1},respectively.The study showed that the measured values of 226Ra and 40K slightly higher than the world wide soil reported in UNSCEAR (2000)..

2- The mean value of total absorbed dose rate is 65.8 nGyh^{-1},which is nearly similar to the world average value of 65nGyh^{-1}.

3- The mean value of the annual dose 0.081 mSv y^{-1},which is lower than the average national and world recommended value of 1.0 mSvY^{-1}. The value of Ra_{eq} activity was found to be less than 370 Bqkg^{-1},the external hazard indices were found to be less than acceptable limit of unity.

Therefore, the study area is still in the zones of normal radiation level, do not pose health risks to the populace of this area.However, this data may provide a general background level for the area studied and may also serve as a guideline for future measurement and assessment of possible radiological risks to human health in this region.

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