DISTRIBUTION OF NATURAL RADIONUCLIDES IN THE SURFACE SOIL OF EASTERN PROVINCE, SAUDI ARABIA

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Abstract - The activity concentrations of natural radionuclides ^{238}U, ^{232}Th and ^{40}K in surface soil samples from Eastern Province, Dammam city, Saudi Arabia were measured by gamma spectrometry using (HPGe) detector. The activity concentration average values of the radionuclides ^{226}Ra, ^{232}Th and ^{40}K in the soil samples ranged from 11.85 – 30.43, 5.74- 15.97 and 362-469 $Bqkg^{-1}$, respectively. with overall mean values of 16.73, 10.40 and 419.99 Bq kg^{-1} respectively. These values are within the world average. The mean value radium equivalent activity value was 63.93$Bqkg^{-1}$, lower the international limit 370$Bqkg^{-1}$. The Representative level index (I_γ), internal and external hazard index (H_{in}, H_{ex}) of all samples under study were less than the limit of unity. The absorbed dose rate due to three primordial radionuclides lies in the range of 24.23 – 39.48 $nGyh^{-1}$ with a mean of 31.68 $nGyh^{-1}$, which yields an annual effective dose of 0.039 $mSvy^{-1}$.The mean value of Excess lifetime cancer risk was calculated as 0.14 x 10^{-3} which is below the World average (0.29 x 10^{-3}). The results obtained in this study are lower than the world recommended values and are found to be safe for the public and environment. The baseline data of this type will almost certainly be important in making estimates of exposure to populations.

Keywords - Soil- Gamma Dose- Radioactivity - Lifetime Cancer Risk

I. INTRODUCTION

Gamma radiations emitted from naturally occurring radioisotopes, such as 40K and 238U, 232Th and their decay products that are present in environmental materials such as soil, rock, water, granite, building materials etc (El-Taher, 2012). Radioactivity distribution in soil results from the rock from which it derives and is based on the nature of its geological formation (UNSCEAR, 2000). Soil not only acts as a source of continuous radiation exposure to humans but also as a medium of migration for the transfer of radionuclides to biological systems (Senthilkumar, & Narayanaswamy, 2016). The soil is an important environmental material which is used for many purposes such as building raw materials and products, for landfilling in playgrounds, for streets etc., containing natural radionuclides that contribute to indoor and outdoor exposure. Therefore, measurement of natural radioactivity in soil is very important to determine the amount of change of the natural background activity with time as a result of any radioactive release. Various studies over the world in the last decades have been done to determine health hazards due to background radioactivity in the soil (Bolat, Onerb, & Çetina, 2017; Rajesh, Kerur, & Anilkumar, 2017; Ismail et al., 2018; Shilpa, Anandaram, & Mohankumari, 2018). 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 few surveys of radioactivity in soils have been carried for different regions (Al-Ghamdi, 2014; El-Taher & Al-Zahrani, 2014; Alashrah, & El-Taher, 2016; Alashrah, 2016). The objective of this study is to measure the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the surface soil samples from Dammam city, Eastern province, Saudi Arabia, to estimate the potential health impact to the human in the area under investigation. The outcomes of this work will form a baseline data set, which will enable the estimations of population exposure. The data will also contribute to the radioactivity mapping of Saudi Arabia surface soils levels.

II. MATERIALS AND METHODS

2.1 Location of Study Area



Fig.1 Location map of Dammam city

The Eastern Province is the largest province by area and is the third most populous province in Saudi Arabia. The Eastern Province is home to most of Saudi Arabia's oil production. The province's capital is the city of Dammam, which hosts the majority of the region's population. Dammam city has an area of 800 Km^2 and it is bound between latitudes 26^0 24\ and longitudes 50^0 08\. The temperature in Dammam city varies from 10°C to 29°C with an average of 15°C. Fig.1 shows the geographical location of this area. This study was carried out to

determine, the concentrations of the natural radionuclides in surface soil from different sampling stations in Dammam city. This area is an industrial region as there are large industrial companies such as for petroleum and chemical factories. This feature makes this region an interesting candidate for radiological studies, although, there is no a study on environmental doses from external exposures before.

2.2 Samples collection and preparation

Surface soil samples (about 0-5 cm) were collected from twenty-three different locations of Dammam city. Each sample was taken with a coring tool within an area of 1 m^2, five cores were taken for each sample, one in the middle and four cores from the corner, these samples were then mixed to make a single sample after removing a top layer of vegetation and roots. The samples were dried at 105^0C for 24h to remove moisture, then subsequently crushed, ground to fine powder, homogenized by passing through a 2 mm test sieve (IAEA., 1989). About 500g of the homogenized soil samples were transferred into cylindrical containers. They were carefully sealed and stored for at least 30 days before gamma-ray analysis was performed to allow ^{226}Ra and its short-lived progenies to reach secular equilibrium.

2.3 Measurements

Gamma spectroscopy measurements were carried by using High Purity Germanium (HPGe) detector with coaxial-type vertical dipstick cryostat (Canberra Model number CPVD 530-15200) P-type with diameter 61 mm، height 54.6 mm. The system has a resolution (FWHM) of (3.0-3.5 keV) for 1332.5 keV gamma-ray peak of 60Co coupled to a computer-based MCA. Spectrum analyzer carried out by using Gamma Vision V6.0 software. The detector was housed inside a massive cylindrical lead shield to reduce the background radiation. Qualitative and quantitative analysis of gamma spectra were processed using the GENIE 2000 program. The spectrometer was tested for its linearity and then calibrated for energy using gamma sources supplied by the International Atomic Energy Agency, Vienna. Counting of samples and background was done for 36000s duration. The activity concentration for 226Ra was determined by using the average obtained by gamma peaks at 351.87 keV (214Pb), 609.31 keV (214Bi) and 1764.49 keV (214Bi), while 232Th from gamma peaks 238.63 keV (212Pb) and 911.21 keV (228Ac) and 40K from 1460 keV gamma peak.

The activity concentrations of the natural radionuclides in the measured samples (A_S) were computed using the following relation (El-Taher and Al-Zahrani, 2014):

A_S (Bq kg^{-1}) = $C_a / \varepsilon P_r M_s$ (1)

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

2.4 Calculation of the Radiological Hazard Indices

2.4.1. Radium equivalent activity

Radium equivalent activity gives a single index, which expresses the gamma yield from a various mixture of 226Ra, 232Th, and 40K in the sample. The radium equivalent activity index was given as (Beretka & Matthew, 1985; UNSCEAR, 2000):

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

where A_{Ra}, A_{Th} and A_K were the radioactivity concentration in Bqkg^{-1} of 238U, 232Th, and 40K. The maximum value of Ra_{eq} must be less than 370 Bqkg^{-1}.

2.4.2. The external and Internal hazard index

To estimate the level of gamma-ray radiation associated with natural radionuclides in specific construction materials is defined by the terms external hazard index (H_{ex}) and internal hazard index (H_{in}) as the following equations (3) and (4), (Beretka & Matthew, 1985):

$H_{ex} = ARa/370 + ATh/259 + Ak/4810$ (3)

$H_{in} = A_{Ra}/185 + A_{Th}/259 + A_K/4810$ (4)

Where ARa, ATh, and AK are the activity concentrations of 226Ra, 232Th and 40K respectively. The values of H_{ex} and H_{in} indices must be less than 1 mSvy^{-1} in order to cause any harmful effect to population (ICRP- 65, 1993).

2.4.3. Representative level index

The representative level index, I_γ is used to estimate gamma radiation associated with the natural radionuclides in soil and calculated by the following equation (NEA-OECD, 1979):

$$I_\gamma = \frac{A_{Ra}}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \quad (5)$$

Where A_{Ra}, A_{Th}, and A_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively in Bqkg^{-1}.

2.4.4. Absorbed gamma dose rate (D)

According to UNSCEAR, 2000, the absorbed gamma dose rate in air 1 m above the ground surface for uniform distribution of natural radionuclide's can be calculated using the activity concentration (A_{Ra}, A_{Th}, and A_K) in (Bqkg^{-1}) and dose conversion factors 0.462, 0.604 and 0.0417 nGyh^{-1}/Bqkg^{-1} for 238U, 232Th, and 40K substituted into the formula

D (nGhy^{-1}) = 0.462 A_{Ra} + 0.604 A_{Th} +0.0417A_K (6)

2.4.5. Annual effective dose (D_{eff})

The annual effective dose equivalent (D_{eff}) was calculated from the absorbed dose (D) by applying the dose conversion factor of 0.7 Sv Gy^{-1} with an

outdoor occupancy factor of 0.2 and 0.8 for indoor (UNSCEAR., 2000) :

(D_{eff}) = D (nG/h) ×8766 (h/year)× 0.7 × (10^3 mSv / nGy 10^9)× 0.2 (7)

2.4.6. Excess lifetime cancer risk (ELCR)

Based upon calculated values of annual effective dose excess lifetime cancer risk (ELCR) was calculated using the following equation;

ELCR= D_{eff} x DL x RF (8)

Where (D_{eff}) is the annual effective dose, DL life expectancy (70 years) and RF (Sv^{-1}) is a fatal risk factor per Sievert, which is 0.05for the public (ICRP-60, 1990).

III. RESULT AND DISCUSSION

3.1. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K

The estimated activity concentrations of the three primordial radionuclides ^{226}Ra, ^{232}Th, and ^{40}K obtained for each of the samples collected from the study region are reported in Table 1. The activity of ^{226}Ra in the soil ranged from 11.85 Bq/kg to 30.43BqKg^{-1} with a mean 16.73 BqKg^{-1} , ^{232}Th ranged from 5.74 BqKg^{-1} to 15.97 BqKg^{-1} with a mean of 10.40 BqKg^{-1} and ^{40}K ranged from 362.62 BqKg^{-1} to 469.12 BqKg^{-1} with a mean of 419.78BqKg^{-1}. The world's mean values of 226Ra, 232Th, and 40K activity concentrations are 32, 45 and 420 Bq kg^{-1}, respectively, (UNSCEAR., 2000). The activity concentrations of ^{226}Ra, ^{232}Th, in all samples were measured to be lower than the world's average values. The high activity of ^{40}K in Some samples may be due to the fact that these samples were collected from areas near the industrial or agriculture lands. The mean activity of ^{232}Th was lower than that of ^{226}Ra, whereas the ^{40}K activity was the highest one and represents the largest contribution about 93% of the total activity (226Ra + 232Th + 40K) in soil , 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 activity concentrations values ^{226}Ra , ^{232}Th and ^{40}K in the soil samples from the study region were shown in Fig.2. A comparison of the mean values obtained in the present work with the same investigations soil of Saudi Arabia and other countries were presented in Table 2. The comparison shows that the values of soils under consideration were comparable with others and were within the world average values as reported by UNSCEAR, 2000. The variations in the concentrations of the radioactivity in the soil of the various locations of the world, depending upon the geological and geographical conditions of the area (UNSCEAR, 2000).

Sample code	Activity concentrations(Bq/kg)			Radium-equivalent (Bq/Kg)
	226Ra	232Th	40K	
S1	13.17±1.84	15.97.±1.13	364.28±3.54	64.06
S2	16.05±1.62	13.28.±1.12	385.91± 3.50	64.76
S3	18.91±1.93	12.58±1.4	442.49± 3.74	70.97
S4	18.89±2.20	10.14±1.58	432.51± 3.62	66.69
S5	19.06±2.11	9.84±1.44	402.56±3.61	64.13
S6	15.80±2.05	5.76±1.48	414.20± 3.75	55.93
S7	11.85±2.09	5.74±1.48	362.62± 3.48	47.98
S8	15.31±1.95	10.21±0.94	379.26±3.26	59.11
S9	16.28±1.94	19.00±1.27	410.88±3.65	75.09
S10	22.57±1.87	8.84 ±1.52	444.16±3.75	69.41
S11	12.58±1.98	5.54 ±1.40	397.56 ± 3.95	51.11
S12	13.56±1.84	12.74±1.22	427.52± 3.64	64.70
S13	8.65±1.75	7.34 ±1.45	432.51± 3.66	52.45

S14	16.48±1.26	12.34±1.30	442.50±3.64	68.20
S15	14.53±1.90	7.94±1.31	424.19±3.70	58.55
S16	17.28±1.99	11.52±1.63	442.49±3.66	67.83
S17	16.61±2.56	7.75±1.66	429.18±3.81	60.74
S18	23.13±2.506	15.14±1.33	469.12±3.85	80.90
S19	18.36±2.59	10.36±1.49	440.83±3.74	67.12
S20	12.78±2.02	12.52±1.56	429.18±3.71	63.73
S21	16.24±2.21	8.11±1.49	439.17±3.66	61.65
S22	16.26±2.03	10.54±1.45	419.20±3.64	63.61
S23	30.43±2.28	6.08±1.44	422.52±3.70	71.66
Min - Max	11.85±2.09 – 30.43±2.28	5.74±1.48- 15.97.±1.13	362.62± 3.48 - 469.12±3.85	47.98 - 80.90
Mean	16.73	10.40	419.78	63.93
World average	32	45	420	370

Table 1 Values of radioactivity concentrations and Radium-equivalent for soil samples under investiga

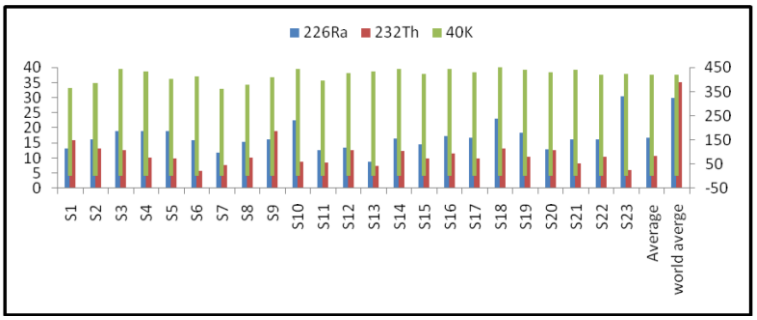


Fig.2 Activity concentrations of 226Ra , 232Th and 40K for surface soil samples Collected from different locations of Dammam city, Saudi Arabia

Country	Mean activity concentration (Bqkg^{-1})			References
	^{226}Ra	^{232}Th	^{40}K	
Saudi Arabia (Dammam)	16.73	10.40	419.78	Present study
Saudi Arabia (Abha)	44.1	29.3	251.5	Ibraheem, El-Taher, & Alruwailia (2018)
Saudi Arabia (AlQasseem)	14.1	15.5	143.1	Alashrah, & El-Taher (2016)
Saudi Arabia (Riyadh)	22.98	21.24	244.97	Al-Sulaiman,& Aboukarima (2016)
Saudi Arabia. (Yanbu city)	40.65	42.89	513.16	AL-Ghamdi (2014)
Nigeria	8.8	17.5	102.8	Ademola, Bello, & Adejumobi, (2014)
Yemen	14. 34	25.78	566.05	Nafee et al., (2017)
Turkey	24.5	51.8	344.9	Durusoy, & Yildirim (2017)
India	30.24	29.89	291.06	Amanjeet et al., (2017)
China	19.5	36.8	728.1	Li et al., (2017)
Egypt , National range	8.64	13.77	141.64	Fares, (2017)

India	30.24	29.89	291.06	Amanjeet et al., (2017)
Algeria	46.7	26.7	246.5	Bramki, Ramdhane,& Benrachi, (2018)
Malaysia	92.23	61.82	621.84	Ismail et al., (2018)
World average	32	45	420	UNSCEAR., 2000

Table 2 Average of specific activity concentrations in the soil at last five years of previous works in some regions of Saudi Arabia and other countries as compared to the present study

3.2. Radiological Hazard Indices

The computed values of (Ra_{eq}) was tabulated in Table 1, where the other indices average values were summarized in Table 3. The following observations can be detected from these Tables (1 and 3):

1) Radium equivalent (Ra_{eq}) in soil samples of study area ranged from 47.98 to 80.90 $Bqkg^{-1}$ with a mean value of 63.93 $Bqkg^{-1}$. All the values of Ra_{eq} in the studied samples are found to be lower than the critical limit 370 $Bqkg^{-1}$ recommend by UNSCEAR, 2000.
2) External and internal hazard index in the study area varied from 0.13 to 0.22 and 0.16 to 0.28 with mean values 0.17 and 0.22, respectively. All these values were below the limit one(UNSCEAR, 2000).
3) 3 - Representative level index (I_γ) for soils varied from 0.19 to 0.31 $Bqkg^{-1}$ with a mean value 0.25 $Bqkg^{-1}$. The external radiation dose within the soil samples is less than the recommended dose of 1 $Bqkg^{-1}$ (UNSCEAR, 2000).
4) The observed value of air absorbed dose rate in soil samples of study area ranges from 24.23 to 39.48 $nGyh^{-1}$ with a mean value of 31.68 $nGyh^{-1}$. It is observed that air absorbed dose rate lies below the population-weighted average value of global primordial radiation of 59 $nGyh^{-1}$ (UNSCEAR, 2000).
5) The annual effective dose in soil samples ranges from 0.029 to 0.048 $mSvy^{-1}$ with an average value of 0.039 $mSvy^{-1}$. which is about 3.9% of the 1.0 mSv $year^{-1}$ as the maximum annual dose as recommended by UNSCEAR, 2000 for an individual member of the public.
6) Cancer risk calculated values are ranged from 0.10 $x10^{-3}$ to $0.16x10^{-3}$ with an average of $0.14x10^{-3}$. These values are lower than the world average ($0.29x10^{-3}$) reported by UNSCEAR, 2000.

Radiation indices	Minimum	Maximum	Mean	UNSCEAR2000
Radium-equivalent (Bq/Kg)	47.98	80.90	63.93	370
External index (H_{ex})	0.13	0.22	0.17	< 1
Internal index (H_{in})	0.16	0.28	0.22	< 1
Representative level index (I_γ)	0.19	0.31	0.25	< 1
Absorbed dose (D) ($nGyh^{-1}$)	24.23	39.48	31.68	59
annual effective dose (D_{eff}) (mSv/y)	0.029	0.048	0.039	1
Cancer risk (*ELCR*)	$0.10x10^{-3}$	$0.16x10^{-3}$	$0.14x10^{-3}$	$0.29x10^{-3}$

Table 3 Mean values of external (Hex) and internal (Hin) azard indices, Representative level (I_γ), absorbed dose rates (D_), annual effective doses ((Deff) and excess lifetime cancer risk (ELCR) for soil samples under investigation

Therefore, based on these results of the radiological hazard, one can conclude that there is no health hazard of the study area and it 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. Comparison of the values of Radium equivalent (Ra_{eq}), absorbed dose (D), the annual effective dose (D_{eff}) for the soil samples were plotted in Fig.3. The results of external (Hex), internal hazard index (H_{in}), level index (Iγ) were presented in Fig. 4. The relative contribution to dose due to ^{40}K was 56.99 %, followed by the contribution due to ^{226}R and ^{232}Th as 22.55 %, 20.46 %, respectively, which were represented in Fig.5.

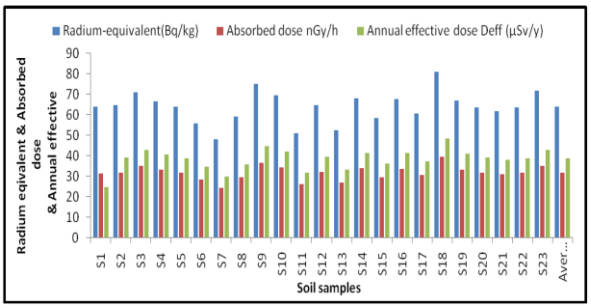


Fig.3 Radium equivalent (Bq/Kg), Absorbed dose rate (nGy/h) and annual effective dose for soil samples from different locations in Dammam city, Saudi Arabia.

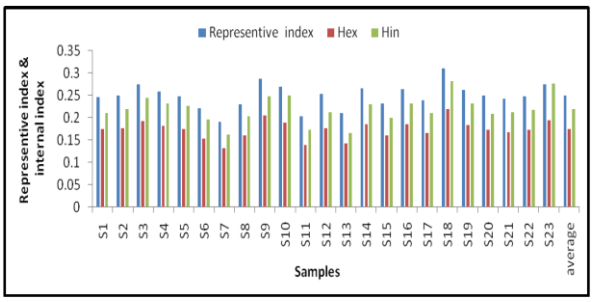


Fig.4 Representative index, external and internal index for soil samples under investigation.

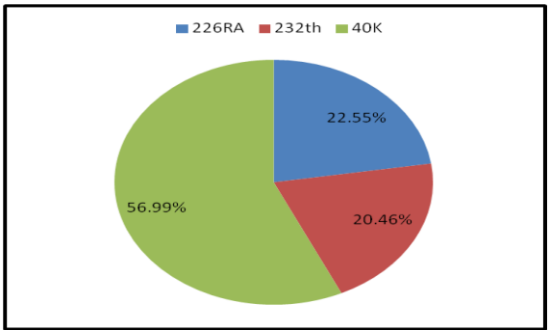


Fig.5 Percentage contribution to the total absorbed dose of ^{226}Ra, ^{232}Th and ^{40}K

IV. CONCLUSION

The average activity concentrations of 226Ra , 232Th and 40 K were 16.73,10.40 and 419.93Bq/kg respectively. The study showed that the measured values are lower than the values in the worldwide soil. The values of the Radium equivalent and absorbed dose rate were 63.93 Bq/kg and 31.68 nGy/h, respectively. These values were lower than the acceptable limits 370 Bq/kg for Radium equivalent and 59 nGy/h, for absorbed dose rate. The external hazard index (Hex), internal hazard index (Hin) and representative level index (Igr) were found to be less than the acceptable limit of unity. The results obtained in this study fall within the range of values reported in similar studies conducted worldwide and are below the values that can cause the significant radiation hazard to the environment and human health and can be used as a building raw materials or other human activities without any radiological risk. However, this data may provide a general background level for the area being 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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