Assessment of natural and anthropogenic radioactivity levels and their radiological hazards in surface soil samples around oil refinery, Aden Assoghra city, Yemen

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Abstract

The activity concentration of global fallout of ^{137}Cs and naturally- occurring radioactive materials (NORM), which primarily due to the geological and geographical condition of soil. and maybe occur from oil and gas burring processes and consequently accumulate on surface soil around the oil refinery in Aden Assoghra city, Yemen were studied by use the gamma-ray spectrometer equipped with a high purity germanium (HPGe) detector and specially designed shield. The average concentrations of ^{226}Ra, ^{232}Th, and ^{40}K expressed in (Bq kg^{-1}) of the studied samples were (13 ± 0.44) Bq kg^{-1}, (22.1 ± 0.64) Bq kg^{-1} and (509 ± 9) Bq kg^{-1}, respectively. Low concentrations of ^{137}Cs were noted from some sample in the study area, where ranged from (0.3 ± 0.2) to (1.7 ± 0.2) Bq kg^{-1}. The average values of calculated radiological hazard indices were 40.6 nGy h^{-1} (absorbed dose rate outdoors), 0.05 mSv y^{-1} (annual effective dose outdoors), 0.279 mSv y^{-1} (annual effective dose indoors), 83.7 Bq kg^{-1} (radium equivalent), 0.23 (external hazard index), 0.26 (internal hazard index), 0.65 (representative level index), 0.174×10^{-3} (the excess lifetime cancer risk ELCR) and 0.292mSv y^{-1} (annual gonadal equivalent dose, AGED).

Keywords: natural radioactivity, gamma-ray spectrometry, radiological hazard indices.

1. Introduction

Naturally occurring radionuclides (NORs) are present at varying concentrations everywhere in the environment. They are present in soil, rocks, water, and food and can be detected in the human body. The predominant natural sources of (NORs) belong to ^{238}U and ^{232}Th series and ^{40}K which are considered of the important responsible of natural external exposure to humans. In the petroleum industry; exploration, extraction and production operation originates minor concentrations of naturally occurring radionuclides (NORs) and accumulate on installation and equipment therefor are indicated as naturally occurring radioactive material (NORM). Also coal, lignite and their combustion residues (fly-ash and bottom-ash or slag) contain naturally occurring radionuclides (NOR), among which the most important are: ^{238}U, ^{226}Ra, ^{210}Pb, ^{232}Th, ^{228}Ra and ^{40}K [10]. Therefore in these industries when their processes increase concentration of (NORM) and then may cause some risk to people if they are not controlled consequently called technologically enhanced naturally occurring radioactive material (TENORM) [2, 11]. The modern development of the nuclear industry, nuclear weapons testing, accident in nuclear power plant (NPP) , and other contaminating technologies become additional sources of anthropogenic radioactive contamination. The knowledge of radioactivity levels of inhabited regions especially nearby several industry facilities such as oil and gas refinery or coal fired thermal power plants is important in the assessment of the probability of radiological hazards to human health. This study aims to measure the natural and artificial radioactivity and determine the associated radiological hazards in the study area.

2. Geological setting

The Republic of Yemen is located in the south of the Arabian Peninsula between latitude 12 - 19 degrees north and longitude 42-55 degrees east longitude. Aden Assoghra city area (~ 485.9 Km^2) is

located some (363 Km) southern of Sana'a, exactly located west of Aden governorate, south of Yemen as shown in fig.1.

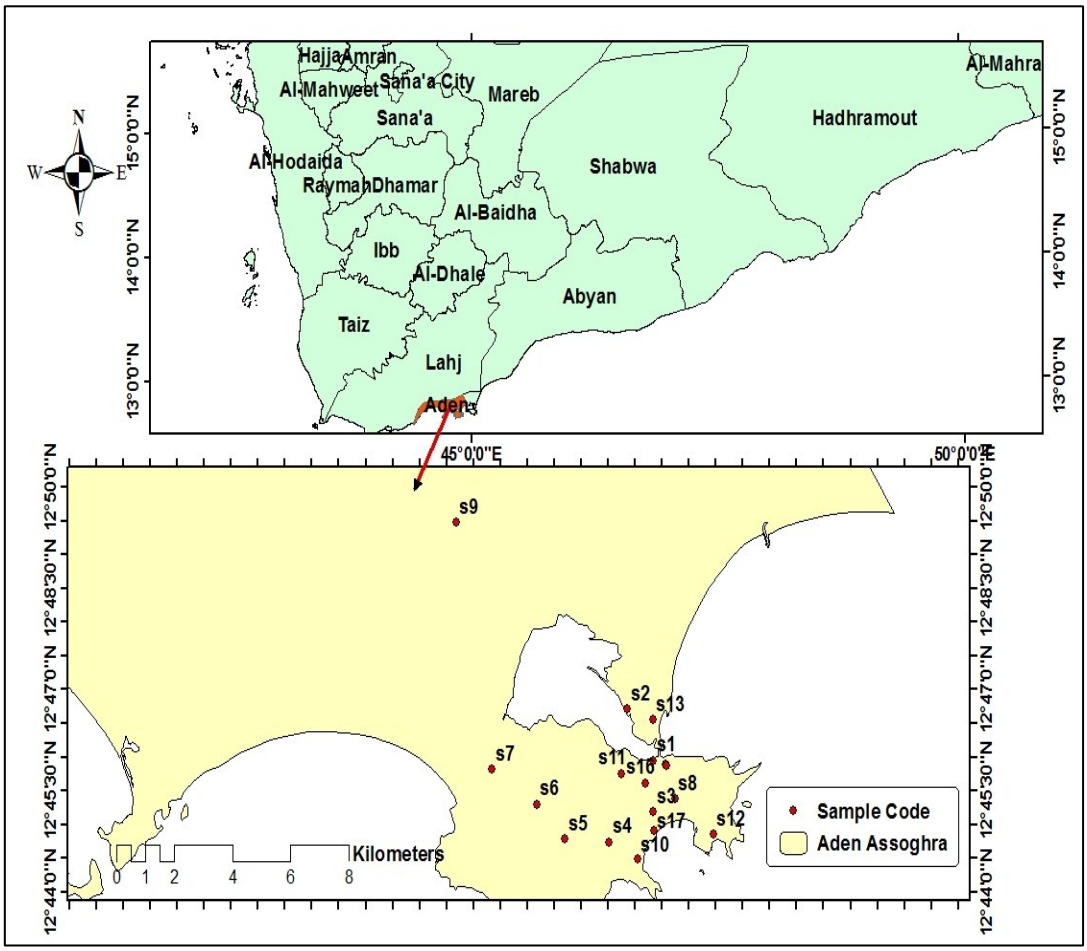

Fig. 1: Location map of areas under study

This city overlooks the coast of the Gulf of Aden, so it is a coastal city, and contain a number of mountainous highlands formed by volcanic origin. The climate of the study area is relatively hot with an average temperature a bought 27 Celsius during the days of the year and the humidity is between (73% - 62%) and is characterized by low rainfall weather. The study area is considered the most important directorate in Aden governorate, which represented more than half Aden governorate area (750 Km^2). The number of population at Aden Assoghra city increase (62405 Souls) Ref [12]. The study area contains oil refinery operating since 1954, as well as oil port and contains the power station that uses a heavy fuel oil and has been operating since 198.

3. Material and methods

3.1 Sampling and sample preparation Seventeen environmental samples (surface soils) were collected from different sites in Aden Assoghra City, Yemen, and prepared for measuring the natural and anthropogenic radioactivity by using gamma spectroscopic analysis according to the following steps; Surface soils were collected randomly from different places within cleared area from the ground surface up to 5 cm and mixed together thoroughly to obtain a representative sample of that area. Each sample (surface soil) was dried in an oven at 105ºC to eliminate the moisture until attained the correct constant weight and was homogenized and pulverized by grinding and sieving through a 18 mesh

(equivalent 1 mm) to gain uniform particle sizes which is the optimum size enriched in heavy mineral [19]. Each samples was packed in previously calibrated plastic containers their dimensions are 75 mm in diameter and 90 mm in height and were filed to a volume 200 ml, and sealed with a lid. The Adhesive paper was placed around the container lid to prevent the radon gas from escaping. Each sample were weighed and stored for a minimum period of about one month to allow daughter products to come from radioactive secular equilibrium between radon and its short-lived decay products.

3.2 Gamma spectrometry – set up and measurements

The activity concentration of investigated radionuclides was performed by using a high purity germanium (HPGe) detector characterized by resolution 1.85 Kev and relative efficiency of 35% at the 1332 Kev ^{60}Co. The detector were shielded in a camper of lead (8 cm thick). energy and efficiency calibrations of the gamma-counting systems were performed by using standard soil sample its volume is 200 ml containing various energies ^{60}Co, ^{88}Y, ^{137}Cs, ^{85}Sr, ^{113}Sn, ^{203}Hg, ^{139}Ce, ^{57Co}, ^{109}Cd and ^{241}Am covering the energy range, 59.54–1836 keV belong to certificate standard sources (R8/31/38 QCY 48) in the selected plastic sample geometry its dimension is 75 mm in diameter and 90 mm height. The background count was determined by containing an empty container having the same dimensions as the one containing the samples and subtracting from the total count. In order to reduce statistical uncertainty, each sample and background were counted for 86,400 seconds. The activity concentration (Bq kg^{-1}) of the individual investigated radionuclide i for a peak at energy E was calculated using the following formula see reference [7]

$$A_{E,i} = \frac{NP}{t_c.I_\gamma(E_\gamma).\varepsilon(E_\gamma).M} \qquad (1)$$

Where NP is the number of counts in a given peak area corrected for background peaks of a peak at energy E_γ, t_c refer to the counting lifetime, $I_\gamma(E_\gamma)$ is the number of gammas per disintegration of this nuclide for a transition at energy E_γ , $\varepsilon(E_\gamma)$ indicate to the detection efficiency at energy E_γ , M is the mass in kg of the measured sample. The 40K and 137Cs concentration were determined directly from 1460.8 and 661.9 Kev gamma line energy respectively. In order to obtain the weighted mean activity concentration of ^{226}Ra from ^{214}Pb (295.21, 351.93) Kev and ^{214}Bi (609.32, 1120.28, 1764.91) Kev. In addition, the weighted mean activity concentration of ^{232}Th was obtain from ^{228}Ac (338.40, 911.20) Kev, ^{212}Pb (238.63) Kev and ^{212}Bi (727.33) Kev. The uncertainty-based weighted mean is used and written according to reference [5]

$$(A)_{avg} = \frac{\sum_{i=1}^{n}\left(\frac{A_{E,i}}{u_c^2(A_{E,i})}\right)}{\sum_{i=1}^{n}\left(\frac{1}{u_c^2(A_{E,i})}\right)} \qquad (2)$$

Where $(A)_{avg}$ is the decay corrected weighted mean activity, n is the number of gamma-ray energies identified and usable, $A_{E,i}$ is the decay corrected activity for the ith gamma ray at energy E, $u_c(A_{E,i})$ is the standard deviation of $A_{E,i}$. Moreover, the weighted mean uncertainty $(u)_{avg}$ estimated according to the fowling formula

$$(u)_{avg} = \frac{1}{\sqrt{\sum_{i=1}^{n}\left(\frac{1}{u_c^2(A_{E,i})}\right)}} \qquad (3)$$

4. Radiological hazards indices

4.1. Radium equivalent activity, Ra_{eq}

Radium equivalent activity, Ra_{eq} defined as an index describes the weighted sum from activities of the ^{226}Ra, ^{232}Th, and ^{40}K radionuclides based on the assumption that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th, and 4810 Bq kg^{-1} of ^{40}K produce the same gamma-radiation dose rate and can be calculated from the following relation see reference [1, 14]

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (4)$$

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

4.2. Hazard index

The external hazard index H_{ex}, is obtained from radium equivalent activity Ra_{eq} by the supposition that allowed maximum value (equal to unity) of the external hazard index corresponds to the upper limit of radium equivalent activity Ra_{eq} (370 Bq kg^{-1}). In addition, the internal hazard index H_{in} produced from internal exposure to ^{222}Rn and its short-lived products, which cause inevitable hazard to the respiratory organs. External hazard index, H_{ex}, and internal hazard index, H_{in} can be obtained from the following relation [1, 6]

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (6)$$

4.3. External absorbed gamma dose rate

The external absorbed gamma dose rates D_γ in outdoor air at 1 m above the ground level, to the population can be calculated from activities of terrestrial radionuclides according to the following formula

$$D_\gamma(nGy\ h^{-1}) = 0.462\ A_{Ra} + 0.604\ 1A_{Th} + 0.0417\ A_K \quad (7)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively, in Bq kg^{-1}. Also 0.462, 0.604 and 0.0417 are the dose conversion factors of A_{Ra}, A_{Th} and A_K, respectively (absorbed dose rate in the air per unit activity per unit mass, in units of nGy h^{-1} per Bq kg^{-1}) reference [17], interestingly that the indoor exposures are in general, 40%greater than outdoor exposures.

4.4. Annual effective dose equivalent

The annual effective doses equivalent outdoors and indoors received by adults can be estimated according to UNSCEAR 1982 report [17] as follows:

$$(AEDE)_{in}(mSv\ y^{-1}) = D_{(\gamma)in}\ nGy\ h^{-1} \times 8760\ h \times 0.7\ Sv\ Gy^{-1} \times 0.8 \quad (8)$$

$$(AEDE)_{out}(mSv\ y^{-1}) = D_{(\gamma)out}\ nGy\ h^{-1} \times 8760\ h \times 0.7\ Sv\ Gy^{-1} \times 0.2 \quad (9)$$

Where 0.7 Sv Gy^{-1} is the conversion coefficient from absorbed dose in air to effective dose received by adults, this value should be changed to 0.8 and 0.9 for children and infants respectively. Values 0.8 ,and 0.2 are the fraction of time spent indoors and outdoors respectively.

4.5. Annual gonadal dose equivalent (AGDE)

The gonads, the active bone marrow and the bone surface cells are highly susceptible to harmful effects of radiation. The annual gonadal dose equivalent (AGDE) due to the specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K is used to measure the population's gonads sensitivity to radiation and evaluated using the following equation [13, 3]

$$AGDE\ (mSv\ y^{-1}) = (3.09 \times A_{Ra} + 4.18 \times A_{Th} + 0.314 \times A_K) \times 10^{-3} \quad (10)$$

4.6. Excess lifetime of cancer risk (ELCR)

The excess lifetime cancer risk (ELCR) indicates the probability of cancer development by an individual over a lifetime due to low radiation exposure level and can be evaluated according to the following formula [3, 15, 16]

$$ELCR = AEDE \times RF \times DL \quad (11)$$

Where AEDE is the annual effective dose equivalent, RF is the fatal cancer risk factor per Sievert (0.05 Sv^{-1}) as mentioned in ICRP-103 and ICRP-106 recommendations and DL is the average duration of lifetime assumed to be 70 years [15, 9].

5. Results and discussion

The activity concentration in (Bq Kg^{-1}) of natural ^{226}Ra, ^{232}Th, ^{40}K and anthropogenic ^{137}Cs in the surface soil samples collected around the refinery in Aden Assoghra City, Yemen were summarized in Table 1. The results confirm that these natural radionuclides were found in all samples at varying concentrations. The activity concentration of ^{226}Ra ranged from 5 ± 0.39 to 17.2 ± 0.46 with an average value of 13 ± 0.44 $BqKg^{-1}$. ^{232}Th values ranged between 7 ± 0.44 to 30.2 ± 0.75 with an average value 22.1 ± 0.64 Bq Kg^{-1}. While ^{40}K values ranged from 210.1 ± 6.1 to 693.9 ± 10 with an average value of 509 ± 9 Bq Kg^{-1}. The average values of ^{226}Ra and ^{232}Th in the study area were lower than the world average values 32 and 45 Bq Kg^{-1} of ^{226}Ra and ^{232}Th respectively. The average value of ^{40}K was higher than the world average value 412 Bq Kg^{-1} [17]. The fallout of ^{137}Cs in the surface soil in the studied area was detected in only five samples and the activity concentration ranged from 1.7 ± 0.2 to 0.3 ± 0.2 with an average value of 0.22 ± 0.05 Bq Kg^{-1}.

Table 1: Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K and ^{137}Cs (Bq kg^{-1}) of surface soil from environment Aden Assoghra city, Yemen

Sample code	Location of Sample	Type of Sample	Activity concentration ($BqKg^{-1}$)			
			^{226}Ra	^{232}Th	^{40}K	^{137}Cs
MRs1	N 12°45.951' E044°53.336'	Sandy soil	14.2 ± 0.48	23.3 ± 0.72	528.9 ± 9.5	*
MRs2	N 12°46.708' E044°52.859'	Sandy soil	11 ± 0.45	22.4 ± 0.7	693.9 ± 11.2	*
MRs3	N 12°45.190' E044°53.336'	Sandy soil	16.9 ± 0.46	28.3± 0.55	564.6 ± 9.5	0.6 ± 0.2
MRs4	N 12°44.740' E044°52.516'	Sandy soil	14.9 ± 0.41	23.6 ± 0.65	496 ± 8.6	*
MRs5	N 12°44.789' E044°51.701'	Sandy soil	6.6 ± 0.38	9.7 ± 0.46	231.2 ± 6.2	*
MRs6	N 12°45.302' E044°51.173'	Sandy soil	15.9 ± 0.46	23.1 ± 0.61	601.7 ± 9.9	0.4 ± 0.1
MRs7	N 12°45.819' E044°50.341'	Sandy soil	12.1 ± 0.57	16.7 ± 0.63	304.1 ± 8.8	1.7 ± 0.2
MRs8	N 12°45.380' E044°53.742'	Sandy soil	13 ± 0.41	20.7 ± 0.58	498.4 ± 8.4	*
MRs9	N 12°49.481' E044°49.675'	Sandy soil	15.6 ± 0.48	26.3 ± 0.73	690.4 ± 10.8	*
MRs10	N 12°44.499' E044°53.058'	Coastal soil	11.7 ± 0.42	18 ± 0.6	433.8 ± 7.8	*
MRs11	N 12°45.757' E044°52.752'	Clay soil	15.1 ± 0.43	28.9 ± 0.78	545.2 ± 9.1	0.7 ± 0.2
MRs12	N 12°44.852' E044°54.458'	Sandy soil	17.2 ± 0.46	30.2 ± 0.75	638.9 ± 10	*
MRs13	N 12°46.551' E044°53.304'	Coastal soil	12 ± 0.4	27.3 ± 0.67	602.8 ± 9.7	*
MRs14	N 12°45.891' E044°53.564'	Sandy soil	12.3 ± 0.41	20.6 ± 0.6	522.3 ± 8.9	0.3 ± 0.2
MRs15	N 12°45.874' E044°53.583'	Sandy soil	11.9 ± 0.42	22.1 ± 0.63	538.8 ± 9.2	*
MRs16	N 12°45.616' E044'53.201'	Sandy soil	14.9 ± 0.41	27.1 ± 0.7	552.6 ± 9.1	*
MRs17	N 12°44.910' E044°53.361'	Coastal soil	5 ± 0.39	7 ± 0.44	210.1 ± 6.1	*
MAX			17.2 ± 0.46	30.2 ± 0.75	693.9 ± 10	1.7 ± 0.2
MIN			5 ± 0.39	7 ± 0.44	210.1 ± 6.1	0.3 ± 0.2
AVERAGE			13 ± 0.44	22.1 ± 0.64	509 ± 9	0.22± 0.05

* Below lower detectable limit.

The range and average values of radium equivalent activity, representative level index ,and external and internal hazard index were estimated in Table 2, and shown in Fig2. From these tabulated results, the Ra_{eq} ranged from 31.1 in sample MRs17 to 109.7 in sample MRs12 with an average 83.7 Bq Kg^{-1} which wasvery much lower than 370 Bq Kg^{-1}. The representative level index $I_{\gamma r}$ results ranged from 0.24 to 0.84 with an average value of 0.65. This result is considered lower than 2 which corresponds to a dose criterion of 0.3 $mSvy^{-1}$. The average values of external and internal hazard indexes were 0.23 and 0.26 respectively which indicates that these results are lower than the unity, thus the radiological risks are negligible in the study area. The average relative contribution to radium equivalent activity owing to ^{226}Ra, ^{232}Th and ^{40}K are 16%, 37%, and 47% respectively as shown in Figure 3a. For the representative level index, $I_{\gamma r}$, It can be seen that the average relative contribution owing to ^{226}Ra, ^{232}Th ,and ^{40}K are 13%, 34%, and 53% respectively as shown in figure 3b, Also ,figure 3c explain that the average relative contribution to the external hazard index, H_{ex} owing to ^{226}Ra, ^{232}Th ,and ^{40}K are 15%, 38%, and 47% respectively.

Table 2: Range and average values for radiological and dose parameters of studied surface soil samples compared with reference values

Radiological and dose parameters	Range	Average	Reference values	Reference
Ra_{eq} (Bq Kg^{-1})	31.1 - 109.7	83.7	370	[1]
$I_{\gamma r}$	0.24 - 0.84	0.65	≤ 2	[4]
H_{ex}	0.08 - 0.30	0.23	1	[6]
H_{in}	0.10 - 0.34	0.26	1	[1]
Dose rate (outdoors) (nGy h^{-1})	15.3 - 52.9	40.6	59	[18]
Dose rate (indoors) (nGy h^{-1})	21.4 - 74.0	56.8	84	[18]
AEDE (outdoors) ($msvy^{-1}$)	0.019 - 0.065	0.050	0.07	[18]
AEDE (indoors) ($msvy^{-1}$)	0.105 - 0.363	0.279	0.41	[18]
AEDE (total) ($msvy^{-1}$)	0.124 - 0.428	0.328	0.48 ≤ 1	[18]
AGDE ($msvy^{-1}$)	0.111 - 0.380	0.292	0.300	[**20**]
ELCR $\times 10^{-3}$(outdoors)	0.066 - 0.227	0.174	0.29	[3,15]

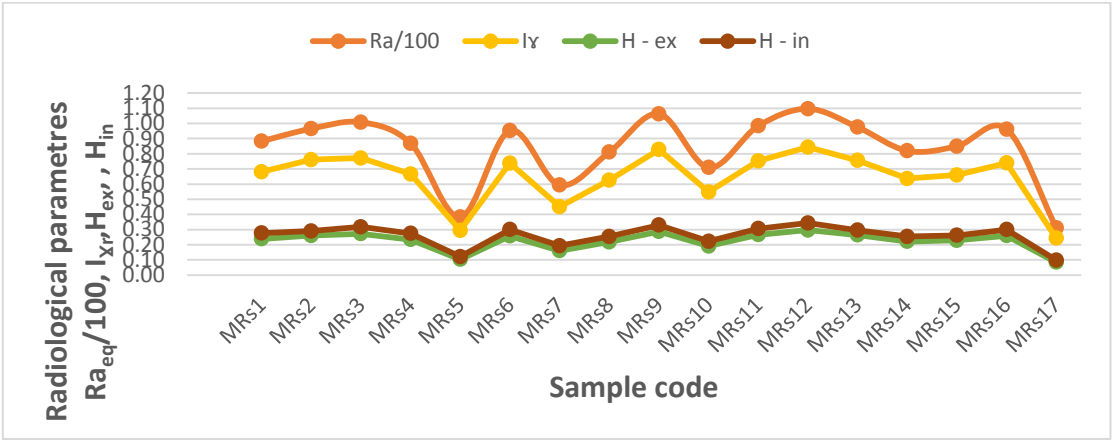

Fig. 2: Values of radiological parameters Ra_{eq}, $I_{\gamma r}$,H_{ex} and H_{in} for sample from study area

The average relative contribution to the internal hazard index, H_{in}, owing to ^{226}Ra, ^{232}Th and ^{40}K are 27%, 33%, and 40% respectively as shown in Fg 3d. The results show that the highest contribution to Ra_{eq}, $I_{\gamma r}$, H_{ex} and H_{in}, owing to ^{40}K followed by ^{232}Th. This result due to the high level of the potassium content in the study area. Whereas the lower contribution to these parameters owing to ^{226}Ra which reflect the lower content of radium in a soil sample. While the content of ^{232}Th is consider moderate compared with the content of ^{226}Ra.

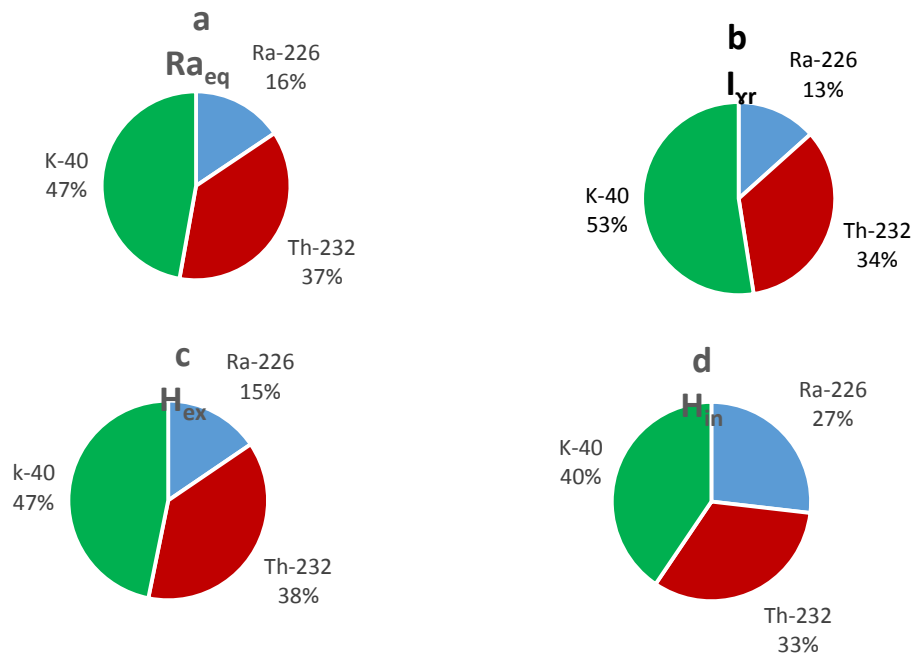

Fig. 3: The average relative contribution to Ra_{eq}, $I_{\gamma r}$, H_{ex}, and H_{in} owing to ^{226}Ra, ^{232}Th, and ^{40}K in studied surface soil samples

The average value of the absorbed dose rate outdoors was 40.6 nGy h^{-1} this result was lower than the world average value 59 nGy h^{-1} **[**18**]**. Fig 4a shows the relative contribution to the absorbed dose rate from external exposure outdoors owing to ^{226}Ra, ^{232}Th ,and ^{40}K. The contribution from ^{226}Ra ranged from a minimum value 11% at sample MRs2 to a maximum value 20% at sample MRs7, corresponding ^{232}Th contribution was from 28% at sample MRs17 to 37% at sample MRs11, ^{40}K contribution from 45% at sample MRs7 to 61% at sample MRs2. The average value of the absorbed dose rate indoor was 56.77 nGy h^{-1}. This result is also lower than the world average value 84 nGy h^{-1}**[**18**]**. The range and average annual gonadal dose equivalent of the study area comparison with the world average were tabulated in Table 2, it can be seen that the annual gonadal dose equivalent ranged from 0.11 to 0.38 with an average value was 0.292 (mSv y^{-1}). This result indicate that the AGDE is similar to the world average value 0.3 mSv y^{-1}. Fig 4b shows the relative contribution to AGDE owing to ^{226}Ra, ^{232}Th ,and ^{40}K, where the contribution owing to ^{226}Ra ranged from 10% as minimum value at sample MRs2 to maximum value at sample MRs7 equal to 18%. The corresponding ^{232}Th contribution was from 26% at sample MRs17 to 36% at sample MRs11. ^{40}K contribution also ranged from 47% at sample MRs7 to 63% at sample MRs2.

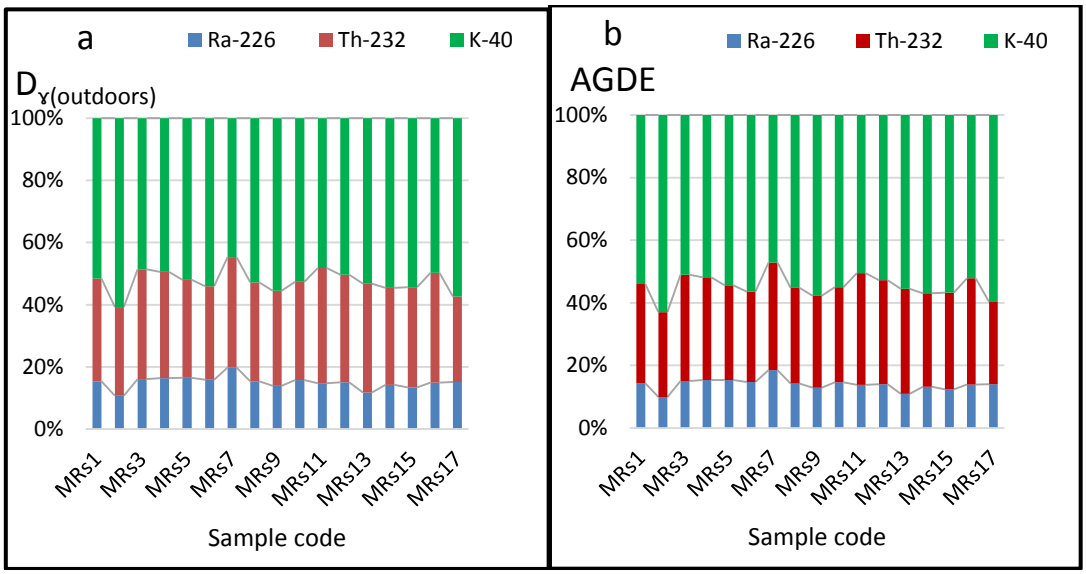

Fig. 4: The relative contribution to Dose rate outdoors nGyh^{-1}, AGDE (mSv y^{-1}) owing to ^{226}Ra, ^{232}Th, and ^{40}K in studied surface soil samples

The average values of outdoor and indoor annual effective doses for adults were 0.05 and 0.27 (mSv y^{-1}) respectively. These results were lower than the worldwide average values 0.07 and 0.41 (mSv y^{-1}) for outdoor and indoor annual effective doses for adults respectively[18]. The total average of annual effective dose was 0.328 (mSv y^{-1}) which was also lower than the worldwide average 0.48 (mSv y^{-1}) and lower than the permissible limit of 1 mSv y^{-1} [8].The excess lifetime cancer risk (ELCR) values were calculated based on annual effective doses equivalent outdoors, these results ranged from 0.066×10^{-3} to 0.227×10^{-3} with an average value 0.174×10^{-3} which is considered lower than the world average value 0.290×10^{-3} , thus the probability of cancer risk due to natural radioactivity in the surface soil at Aden Assoghra city, Yemen is negligible.

5. Conclusions

The radionuclides which firstly due to the geological and geographical condition of soil and may be produced, from oil burning which accumulated at surface soil of Aden Assoghra city, Yemen were measured utilizing high purity germanium (HPGe) gamma ray spectrometry in the national atomic energy commission laboratory, Sana'a Yemen. The main natural radionuclides were present in all studied surface soil samples in different concentrations. The average activity concentration values were 13 ± 0.44 Bq Kg^{-1} for ^{226}Ra and 22.1 ± 0.64 Bq Kg^{-1} for ^{232}Th. While ^{40}K values was 509 ± 9 Bq Kg^{-1}. Although the study area contains an oil refinery, fortunately, low levels of radioactivity were observed. There are a number of reasons that explain these low levels of radioactivity deposited on the surface soil. Stopping the refinery in operation during the past years. The location and climate of the study area also earn a significant role in the decontamination of the study area. Heavy seasonal rains may cause the dissolving of the radionuclides in water nevertheless uranium and thorium are not soluble in water, but their radioactive decay product, such as radium, and some of their decay products are somewhat soluble. Therefore, radium and its decay products may dissolve in water and drift to the sea, especially in sloping areas, or cause the sinking of the radionuclides to low depths the surface soil. The fallout of ^{137}Cs in surface soil in the studied area was detected in only five samples their average value of activity concentration was 0.22 ± 0.05 Bq Kg^{-1}. The average values of radium equivalent activity, representative level index, and external and internal hazard index were at low levels; thus the radiological risks are negligible in the study area. Also the average values of absorbed dose rate outdoor and indoor were lower than the world average values 59 nGy h^{-1} and 84 nGy h^{-1}

respectively. The average values of outdoor and indoor annual effective dose for adults were 0.05 and 0.27 (mSv y^{-1}) respectively. The total average of annul effective dose was 0.328 (mSv y^{-1}) these results were lower than the worldwide average values [8**]**. Similar values for infants and children were higher than adults. The average value of annual gonadal dose equivalent was 0.292 (mSv y^{-1}) this result indicate that the AGDE is similar to the world average value 0.3 mSv y^{-1}.

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تقييم مستويات النشاط الإشعاعي الطبيعي والبشري ومخاطرها الإشعاعية في عينات تربة سطحية حول مصفاة النفط، مدينة عدن الصغرى، اليمن

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الملخص

تركيز الفعالية الإشعاعية من الغبار الذري العالمي للسيزيوم-137 والمواد المشعة التي تحدث بشكل طبيعي والتي ترجع أساسًا إلى الحالة الجيولوجية والجغرافية للتربة. وقد تحدث من عمليات احتراق النفط والغاز وبالتالي تتراكم على التربة السطحية حول مصفاة النفط في مدينة عدن الصغرى، اليمن تمت دراستها باستخدام مطياف أشعة جاما المجهزة بكاشف جرمانيوم عالي النقاء ودرع مصمم خصيصًا. متوسط تراكيز الراديوم-226، الثوريوم-232، والبوتاسيوم-40 معبرًا عنها بوحدة بيكرل/كجم للعينات المدروسة كانت 13±0.44، 22.1 ±0.64، و509±9 بيكرل/كجم على التوالي. لوحظ تركيز منخفض للسيزيوم-137 من بعض العينات في منطقة الدراسة، حيث تراوحت بين (0.2±0.3) إلى (0.2±1.7) بيكريل/كجم.

كانت القيم المتوسطة لمؤشرات المخاطر الإشعاعية المحسوبة 40.6 نانو جراي/ساعة (معدل الجرعة الممتصة في الهواء الطلق)، 0.05 ملي سيفرت/سنة (الجرعة الفعالة السنوية في الهواء الطلق)، 0.279 ملي سيفرت/سنة (الجرعة الفعالة السنوية الداخلية)، 83.7 بيكريل/كجم (المكافئ الراديومي)، 0.23 (مؤشر الخطر الخارجي)، 0.26 (مؤشر الخطر الداخلي)، 0.65 (مؤشر المستوى التمثيلي لأشعة جاما)، 0.174 × 10^{-3} (خطر الإصابة بالسرطان مدى الحياة) و0.292 ملي سيفرت/سنة (الجرعة السنوية المكافئة للغدد التناسلية).

الكلمات المفتاحية: النشاط الإشعاعي، مطياف أشعة جاما، مؤشرات المخاطر الاشعاعية.