Assessment of radiation hazard indices for sand samples from Ma'rib in Yemen

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ABSTRACT

Background: This study aimed to investigate the radiation hazard indices from sand samples of Ma'rib Governorate in Yemen, where the majority of oil and gas facilities are installed. ***Methods and Materials:*** Thirty five samples of desert sand from Ma'rib Governorate in Yemen were collected and tested their radiation hazard indices by using High Purity Germanium (HPGe) detector. ***Results:*** Based on the measurement of the concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, the radium equivalent activity (Ra_{eq}), the activity concentration index ($I_γ$), the external hazard index (H_{ex}) and the internal hazard index (H_{in}) were all calculated. Also, the absorbed dose rate in Air (ADR) and the annual effective dose (AED) are calculated. ***Conclusions:*** Comparing the practically attained results with internationally permissible values, it was found that most of the radiological parameters, including the radiation hazard indices of the studied samples, fall within the world's permissible limits and don't expose risks to the human beings and environments.

Keywords: *Natural radioactivity, sand samples, HPGe detector, annual effective dose.*

INTRODUCTION

Naturally occurring radioactive materials (NORMs) are found in rocks, soil, sand, and water since the formation of the Earth. Some of these radioactive materials have very long half-lives for dissolution (hundreds of millions years or more). A large quantity of these nuclides is still present on the Earth until now. Human's and technological activities may lead to enhancement of these materials to higher levels, in such case, these are called technologically enhanced naturally occurring radioactive materials (TENORM) [(1-4)].

One of the most important types of environmental pollution is radioactive pollution, which is the spread of radioactive materials in topsoil, sand, rocks, and water, whether this spread is natural or as a result of anthropogenic activities.. Therefore, a lot of studies and surveys of air, soil, sand, rocks, water, food, and others have been conducted to measure the level of radiation doses to which inhabitants of this planet are exposed continually [(5-9)].

The International Atomic Energy Agency (IAEA) and the US Environmental Protection Agency (EPA) have published guidelines for tracking exposure to natural radiation for human health. Soils, sand, and sediments are amongst some sources of human exposure to natural radiation. Radiation sources may also transmit to our food and biological chain from the soil, causing extra health risks. The food chain is one of the major pathways for the migration of radioactive pollutants. Humans are mainly exposed to natural radiation that originates mostly from above 30 cm above the Earth's surface. Since these radionuclides are not uniformly distributed, knowledge of their distribution in soil, sand, and rocks plays an important role in radiation dose measurement and protection [10-12].

The petroleum industry and the residues of its derivatives are all considered as radioactive pollutants to human health. The groundwater wells contain large quantities of formation water along with crude oil. This water contains naturally radioactive materials that are transported to the Earth's surface during the extraction process. These materials pose a great danger to the environment in the areas of production, refining, and distribution, as well as across various transmission lines [3, 4].

Upon contamination with such radioactive materials, the air, soil, and water environments are adversely affected. Accordingly, the responsible of petroleum industries are concerned with managing this issue by recycling the oil wastes through costly processes and via high technologies. Therefore, studying the radiological hazards resulting from oil industries has magnetised great attention of researchers nowadays all over the world to reduce the remains of such environmental risks. However, more investigations regarding these hazards and its negative impacts are still required [3, 4, 13].

The desert region of Ma'rib in Yemen is a potential area for radioactive consequences. Therefore it is desirable to conduct a study in this region. This is the first time that such a study has been conducted. In light of this, the current study aims to asses the indicators of radiological hazards, generated by oil and gas industries, for sand samples in Ma’rib desert in Yemen. This article mainly addresses the parameters including radium equivalent activity (Ra_{eq}) activity concentration index ($I\gamma$), external hazard index (H_{ex}), internal hazard index (H_{in}), absorbed dose rate in the air (ADR) and annual effective dose (AED) of the radioactivity concentration of the ^{238}U, ^{232}Th, and ^{40}K in sand samples obtained from different locations in Ma'rib. Moreover, this study can be used to set a reference line for further work in the future , focusing on the radioactivity level in this territory.

MATERIALS AND METHODS

Geology of study area

Governorate of Ma’rib in the central of Yemen, which is located in the northeastern part of Sana'a, the capital of Yemen. located between latitude (15° 23' 40.73", 16° 7' 29.55"N) and longitude (45° 10'32.28", 44°46'33.83"E) at an altitude of 944 meters above sea level. Google Earth and GPS were used to record the exact coordinates of the collected samples from the study area, as shown in figure 1 and table 1. This desert area has less rainfall throughout the year, due to which the agriculture of this area is greatly affected. The Governorate of Ma'rib is the first of the Yemeni governorates where most of the production and processing facilities of oil and gas are installed since 1986 [14, 15].

Sample collection and processing

Thirty-five sand samples were collected from various sites of Ma'rib desert centre, and its borders and their geological coordinates are given in figure 1 and table 1. The collected sand samples are categorised as "SO" and "SN". All samples in category "SO" were collected from inside and nearby surroundings of the oil and gas facilities, where a total of twinty one samples were collected. All other samples in category "SN" were taken from sites that have no history of oil exploitation and production but with similar geographic and geological characteristics to oil and gas societies, where a total of twinty one samples were collected. The samples collected in a manner consistent with the achievement of the study objectives. Each sand sample was taken directly from natural exposures from surface pits at a depth of 20-50 cm from the outer surface. All organic materials larger than 1 mm in size were excluded from the collected samples. These samples were subsequently transported to the laboratory for further process and analysis.

In the laboratory, the samples were dried, ground, and sieved. All prepared samples were kept in unused plastic containers.

Radioisotopes for sand samples were determined by taking a volume of 65 mL from each sample. The samples were kept in tightly closed containers (Petri Dish). The Petri dishes were sealed tightly to avoid any leakage of radon. Prior to measurements, samples were preserved at same conditions by leaving in the laboratory for one month to ensure the secular equilibrium of radium isotopes and their short-lived decay products.

Table 1. Location coordinates values.

Simple	Region Name	Position	
		Longitude(°E)	Latitude(°N)
SO_{1}	Almazarie	45°47'23.74"	15°33'32.45"
SO_{2}	Kara	45°48'58.56"	15°31'36.46"
SO_{3}	Al jamil	45°46'2.25"	15°32'22.40"
SO_{4}	Aljathua	45°41'13.47"	15°32'45.41"
SO_{5}	Alhani	45°44'45.85"	15°35'42.01"
SO_{6}	Alhazma	45°33'3.41"	15°33'31.91"
SO_{7}	Alrubue	45°49'19.14"	15°35'41.79"
SO_{8}	Alramsa	45°43'57.47"	15°30'8.68"
SO_{9}	Alearaqa	45°35'27.57"	15°30'28.25"
SO_{10}	Alghawia	45°30'31.14"	15°30'46.97"
SO_{11}	Alghajla	45°39'8.27"	15°27'18.24"
SO_{12}	Sulua	45°45'16.15"	15°27'10.47"
SO_{13}	Almumlah	45°56'27.38"	15°37'14.14"
SO_{14}	Al shabwan	46° 0'15.73"	15°39'41.10"
SO_{15}	Althaman	45°59'8.61"	15°36'45.72"
SO_{16}	Alkhushea	46° 1'55.71"	15°37'21.73"
SO_{17}	Alshaykh	45°58'46.52"	15°33'17.33"
SO_{18}	Alshamar	45°58'1.37"	15°36'20.28"
SO_{19}	Aljudean	45°52'26.39"	15°35'2.77"
SO_{20}	Alrashid	45°50'11.39"	15°40'11.06"
SO_{21}	Al misheal	45°57'28.71"	15°27'2.41"
SN_{1}	Jawalnasim	46°32'39.29"	16° 0'26.08"
SN_{2}	Alhusuwn	46°18'35.01"	15°58'1.31"
SN_{3}	Alghajla	46°25'1.88"	15°50'32.40"
SN_{4}	Al jalal	46° 4'38.83"	15°52'56.42"
SN_{5}	Al fajayh	46°13'6.36"	15°43'28.38"
SN_{6}	Al jabir	45°40'52.39"	15°44'51.41"
SN_{7}	Alhuma	45°27'2.06"	15°37'46.31"
SN_{8}	Fyfil	45°31'55.25"	15°23'18.87"
SN_{9}	Al misheal	45°40'54.69"	15°21'48.72"
SN_{10}	Althania	45°33'51.04"	15°16'16.37"
SN_{11}	Al qazea	45°43'51.18"	15°15'4.23"
SN_{12}	Alhaway	45°52'38.20"	15°22'53.78"
SN_{13}	Altahil	45°53'29.61"	15°45'7.70"
SN_{14}	Al munif	46°14'14.33"	15°37'38.31"

SO is a sample taken from oil societies.
SN is a sample taken from non-oil societies.

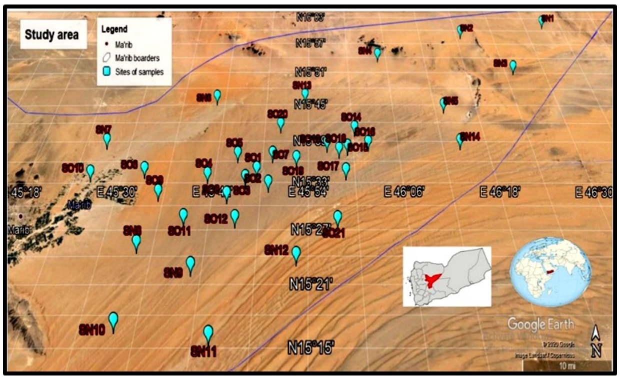

Figure 1. Sample sites are shown on google earth map, and detailed coordinates are recorded in table 1.

Analysis of radiation hazard indices

Each sample was then measured at a record time of 64,800 seconds using Gamma-ray spectroscopy system of Canberra N-type equipped with a high purity germanium detector (HPGe). The background radiation spectrum was used to determine the minimum detectable activity. The detector has a relative efficiency of 35% and a resolution of 1.85.

KeV for 1332 KeV gamma energy of ^{60}Co. The detector is surrounded by a lead shield of 10 cm thickness to reduce the background radiation levels of the system, as well as, lined from the inside with copper plates of 1 mm thickness to minimise the X-ray emitted by

Table 2. The gamma-ray and its radioisotopes used to calculate the radioactivity concentrations of TENORM in sand samples.

Nuclide	Gamma-ray energy (KeV)	Radioisotope
^{226}Ra	609.32, 1120.28 and 1764.91	^{214}Bi
	295.21 and 351.93	^{214}Pb
^{232}Th	338.40, 911.20	^{228}Ac
^{40}K	1460.83	^{40}K

Where, A is the radioactivity concentrations, N_{net} is the net area under photo-peak, Ɛ is the efficiency of the detector, $I\gamma$ is the transition probability of the emitted gamma-ray (Effectiveness concentration factor), m is the sample weight in kilograms, t is the time for the collected spectrum (in seconds). Depending on the activity concentrations of the radioactive nuclides of ^{226}Ra, ^{232}Th, and ^{40}K, various radiation hazard indices are calculated as follows:

Radium Equivalent Activity (Ra_{eq})

The value of the equivalent activity of radium (Ra_{eq}), which is used to estimate the risk of the concentration due to the effectiveness of ^{226}Ra, ^{232}Th, and ^{40}K in units of $Bq.kg^{-1}$ is evaluated according to equation 2 (19-23).

$$Ra_{eq}(Bq.kq^{-1})=A_{Ra}+1.43\times A_{Th}+0.077A_K \quad (2)$$

Where, A_{Ra}, A_{Th}, and A_K are represent the radioactivity concentrations of radium, thorium, and potassium, respectively, and the highest value of (Ra_{eq}) must be less than the global tolerance limit of (370 $Bq.kq^{-1}$) (17).

Activity Concentration Index (Iγ)

The activity concentration index is a coefficient used to calculate the risk arising from the radiation of gamma coupled with nuclides (^{226}Ra, ^{232}Th, and ^{40}K) in the studied samples and is estimated by by equation 3 (20, 21, 24).

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (3)$$

External Hazard Index (H_{ex})

External hazards represent the ionised hazards of the natural external gamma radiation. The aim is to ensure that the effective dose of this radiation does not exceed the permissible limits. The hazard coefficient is calculated evaluated using equation 4 (20, 22, 24).

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (4)$$

Internal Hazard Index (H_{in})

Inhaling alpha particles emitted from short-lived isotopes such as radon and thoron, that are accompanied by gamma-rays having different energies, which can be expressed by the internal hazard index as per the equation 5 (20, 22, 24).

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

The amount of internal risks is preferable to be less than one in the ideal environment to ensure workplace safety of the respiratory organs and for the survival of individuals.

Absorbed Dose Rate in Air (ADR)

The total percentage of the absorbed dose rate in the air can be calculated in terms of the concentrations of terrestrial nuclei by equation 6 (20-24).

$$ADR(nGy.h^{-1})=0.462A_{Ra}+0.621\times A_{Th}+0.0417\times A_K \quad (6)$$

Annual Effective Dose (AED)

In order to calculate the annual effective dose, (the conversion factor from the absorbed 105 dose, and the internal occupancy factor) must be considered. UNSCEAR 2000 has published the 0.7 Sv/Gy as a conversion factor from the dose absorbed of the gamma-ray emitter in the air to the annual effective dose received by adults. Assuming 0.20 is the ratio of time spent outdoors, where the number of hours in a year are considered to be 8760. accordingly, the annual effective dose can be evaluated by equations7 (11, 20, 23, 24).

$$AED\,(\mu Sv.y^{-1}) = AD\left(\frac{nGy}{h}\right) \times 10^{-6} \times 8760\frac{h}{y} \times 0.20 \times 0.7\frac{Sv}{Gy} \quad (7)$$

The annual effective dose (AED) of outdoor gamma radiation is preferably less than the global average of 460 $\mu Sv.y^{-1}$. Radiation hazard indices were calculated and the results are are summarised in tables 3 and 4.

Statistical analysis

The IBM SPSS-25 computer program was used to perform all the statistical assessments. Due to the non-parametric data set, the iterative distribution of the data was tested against the normal or logarithmic normal distribution by the Kolmogorov-Smirnov test (K-S) at the significance level ($p>0.05$).

Statistical significance differences were calculated between samples taken from oil and non-oil societies using Mann-Whitney test (M-W) at the significance level ($p<0.05$). The average, variance, standard deviation, minimum, maximum, skewness (degree of symmetry degradation) and kurtosis factor (peak degree) parameters were counted. The statistical data are summarised in tables 3, 4 and 5.

Table 3. Radiation hazard indices for sand samples collected from Ma'rib region of Yemen (category "SO").

Simple	Ra_{eq} $Bq.Kg^{-1}$	Iγ	Hex	H_{in}	ADR $nGy.h^{-1}$	AED $(\mu Sv.y^{-1})$
SO_1	116.376	0.914	0.325	0.356	57.500	70.518
SO_2	95.337	0.756	0.264	0.303	47.846	58.679
SO_3	71.638	0.572	0.195	0.245	36.565	44.843
SO_4	105.186	0.807	0.292	0.366	51.566	63.241
SO_5	97.842	0.765	0.272	0.318	48.457	59.428
SO_6	76.945	0.623	0.210	0.249	39.577	48.537
SO_7	112.536	0.873	0.311	0.383	55.671	68.275
SO_8	83.907	0.657	0.229	0.304	42.313	51.893
SO_9	104.966	0.817	0.293	0.333	51.605	63.289
SO_{10}	68.275	0.544	0.190	0.206	34.223	41.971
SO_{11}	85.746	0.681	0.237	0.270	43.080	52.833
SO_{12}	71.830	0.581	0.196	0.231	36.873	45.221
SO_{13}	55.837	0.467	0.152	0.165	29.400	36.057
SO_{14}	68.270	0.555	0.187	0.215	35.166	43.128
SO_{15}	108.741	0.853	0.303	0.340	53.765	65.937
SO_{16}	72.082	0.580	0.197	0.238	36.910	45.266
SO_{17}	106.282	0.836	0.295	0.335	52.792	64.744
SO_{18}	96.664	0.761	0.268	0.312	48.241	59.163
SO_{19}	106.548	0.834	0.294	0.355	53.031	65.037
SO_{20}	101.588	0.793	0.281	0.339	50.407	61.819
SO_{21}	99.572	0.774	0.276	0.334	49.247	60.396
Min	55.837	0.467	0.152	0.165	29.400	36.057
Max	116.376	0.914	0.325	0.383	57.500	70.518
Ave.	90.770	0.716	0.251	0.295	45.440	55.727
a	370	1≤	1≤	1≤	55	460

a Worldwide average value (UNSCEAR, 2000)[19].

Table 4. Radiation hazard indices for sand samples collected from the Ma'rib region of Yemen (category " SN")

Simple	Ra_{eq} $Bq.Kg^{-1}$	Iγ	Hex	H_{in}	ADR $nGy.h^{-1}$	AED $(\mu Sv.y^{-1})$
SN_1	90.487	0.719	0.250	0.287	45.506	55.809
SN_2	84.483	0.673	0.235	0.255	42.333	51.917
SN_3	87.969	0.699	0.244	0.275	44.130	54.121
SN_4	72.969	0.579	0.202	0.231	36.642	44.938
SN_5	74.232	0.585	0.204	0.252	37.317	45.765
SN_6	70.679	0.570	0.193	0.230	36.262	44.471
SN_7	67.671	0.546	0.185	0.220	34.698	42.554
SN_8	72.404	0.580	0.198	0.240	36.974	45.345
SN_9	74.840	0.603	0.206	0.230	38.019	46.627
SN_{10}	60.421	0.489	0.166	0.185	30.819	37.797
SN_{11}	88.400	0.699	0.244	0.288	44.358	54.401
SN_{12}	103.968	0.824	0.289	0.318	51.834	63.570
SN_{13}	74.008	0.594	0.203	0.238	37.704	46.240
SN_{14}	61.244	0.510	0.167	0.180	32.107	39.376
Min	60.421	0.489	0.166	0.180	30.819	37.797
Max	103.968	0.824	0.289	0.318	51.834	63.570
Ave.	77.413	0.619	0.213	0.245	39.193	48.066
a	370	1≤	1≤	1≤	55	460

a World wide average value (UNSCEAR, 2000)[19].

Radiographic maps

Radiographic maps were made graphically using the applications Google Earth, TCX 2.5 Converter, Server 9, and Excel software systems. The coordinates of the collected samples were read from GPS. The digital height model for the study area was created by digitising contour lines from standard topographic maps. Radiological maps were made for the most important radiological hazards indicators Ra_{eq} and H_{in} as in figures 2 and 3.

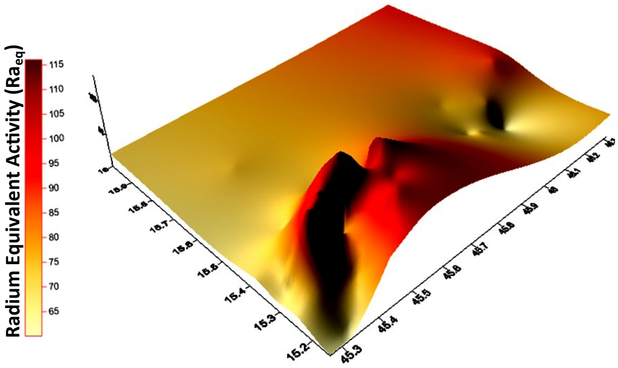

Figure 2. Distribution map of radium equivalent activity (Ra_{eq}).

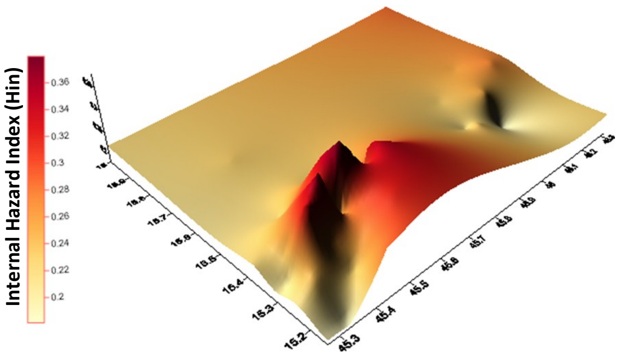

Figure 3. Distribution map of internal hazard index (H_{in}).

RESULTS

Tables 3 and 4 summarise the results of the radiation hazard indices for this research work. The obtained findings are used to construct contour maps, illustrating the variation in the concentration values of the radiation hazard indices and portraying how these hazards are distributed over the studied areas as shown in figures 2 and 3. Furthermore, the results are compared with the permissible global averages.

For oily samples (SO), Ra_{eq} ranged from 55.84 to 116.38 $Bq.kg^{-1}$, with an average of 85.43 $Bq.kg^{-1}$. I_γ, H_{ex} and H_{in} ranged between 0.47-0.91, 0.15-0.33 and 0.17-0.38 respectively, and the averages are found to be 0.68, 0.24 and 0.28 respectively. ADR ranged between 29.40-57.50 $nGy.h^{-1}$ with an average of 42.94 $nGy.h^{-1}$. AED ranged between 36.06 - 70.52 $\mu Sv.y^{-1}$, and the average is found to be 52.66 $\mu Sv.y^{-1}$. While for non – oily samples (SN), Ra_{eq} ranged from 55.84 to 116.38 $Bq.kg^{-1}$, with an average of 85.43 $Bq.kg^{-1}$. I_γ, H_{ex} and H_{in} ranged between 0.47-0.91, 0.15-0.33 and 0.17-0.38 respectively, and the averages are found to be 0.68, 0.24 and 0.28 respectively. ADR ranged between 29.40-57.50 $nGy.h^{-1}$ with an average of 42.94 $nGy.h^{-1}$. AED ranged between 36.06-70.52 $\mu Sv.y^{-1}$, and the average is found to be 52.66 $\mu Sv.y^{-1}$. The obtained results were compared with the permissible global average values, and all radiation hazard indices were found to

be less than these. This confirmed that there are no current radiological hazards, neither on health nor the surrounding environment. Despite this, the statistical K-S and M-W tests between the oily and non-oily samples showed that there are statistically some differences at the significance level ($p<0.05$) for the benefit of the oily samples, as shown in table 5. The results also illustrated that the radiation hazard indices differ from one region to another, as the highest values of Ra_{eq}, Iγ, H_{ex}, ADR, and AED for oily samples are at Almazarie (position 8), and the lowest values are at Almumlah (position 26). As for H_{in}, the highest value is at Alrubue (position 14), and the lowest value is at Almumlah (position 26). Concerning the non- oily samples, the highest values of Raeq, Iγ, H_{ex}, ADR and AED are at Alhaway (position 24), and the lowest values are at Althania (position 22). As for Hin, the highest value is at Alhaway (position 24), and the lowest value is at Almumlah (position 35). To clarify the distribution of these indices in the study area. The pictorial map for Raeq. is shown in figure 2. Moreover, in each study area, the other indices, I_γ, Hex, ADR, and AED showed the same behavior as the Raeq. Figure 3 shows the radiation hazard map of Hin.

Table 5. Descriptive statistics for all sand samples.

indice	Sample Type	Variance	Std. Dev.	Skewness	Kurtosis	K. S. Test		M. W. Test	
						Z	Sig.	Z	Sig.
Ra_{eq}	SO	311.071	17.367	-0.401±0.501	-1.127±0.972	1.449	0.030	-2.088	0.037
	SN	147.829	12.159	0.657±0.597	0.191±1.154				
Iγ	SO	0.017	0.129	-0.354±0.501	-1.135±0.972	1.449	0.030	-2.088	0.037
	SN	0.008	0.917	0.752±0.597	0.3231±1.154				
H_{ex}	SO	0.003	0.050	-0.382±0.501	-1.159±0.972	1.449	0.030	-2.088	0.037
	SN	0.001	0.346	0.677±0.597	0.185±1.154				
H_{in}	SO	0.004	0.061	-0.566±0.501	-0.720±0.972	1.587	0.013	-2.458	0.014
	SN	0.001	0.383	0.081±0.597	-0.065±1.154				
ADR	SO	66.591	8.160	-0.394±0.501	-1.097±0.972	1.449	0.030	-2.054	0.040
	SN	32.942	5.740	0.6941±0.597	0.279±1.154				
AED	SO	100.156	10.008	-0.394±0.501	-1.097±0.972	1.449	0.030	-2.054	0.040
	SN	49.546	7.039	0.6941±0.597	0.279±1.154				

DISCUSSION

In this study, radiation hazard indices Ra_{eq}, I_γ, H_{ex}, H_{in}, ADR, AED_{indoor} and $AED_{outdoor}$ were determined for thirty five sand samples in Ma'rib - Yemen using Gamma-ray spectrometry system with HPGe detector. The results of these measurements showed that the averages of Ra_{eq}, I_γ, H_{ex}, H_{in}, ADR and AED for oily samples were 90.770 ($Bq.Kg^{-1}$), 0.716, 0.251, 0.295, 45.440 ($nGy.h^{-1}$), and 55.727($\mu Sv.y^{-1}$), respectively. As for non-oily samples, they were 90.770 ($Bq.Kg^{-1}$), 0.716, 0.251, 0.295, 45.440 ($nGy.h^{-1}$), and 55.727 ($\mu Sv.y^{-1}$), respectively.

These values compared with the world values reported by UNSCEAR 2000 [17] were lower.

However, K-S and M-W tests were performed on the raw data to distinguish the differences between the oily and non-oily samples, at significance level ($P<0.05$). K-S and M-W tests indicate statistically significant differences in favour of sample from oily societies. The differences in the distribution of the Ra_{eq}, I_{γ}, H_{ex}, H_{in}, ADR, and AED might have resulted from the contribution of the oil and gas industries and the geology of the study area.

The radiation hazard indices of sand samples were compared with results obtained by other researchers in different areas of oil and gas societies around the world, as shown in table 6. From table 6, the minimum value of Ra_{eq} in this work is higher than the ones in Egypt, Turkey, and Kuwait, and less than the ones recorded in Saudi Arabia [25] and China [26]. The maximum value is higher than the ones in Egypt, Turkey, Saudi Arabia, and Kuwait, and less than the value in China. The minimum and maximum values of I_{γ} are higher thanthe ones in Egypt and Kuwait. The minimum and maximum values of H_{ex} are higher than the values in Egypt, Turkey, and Kuwait, and less than the recorded ones in Saudi Arabia and China. The minimum and maximum values of H_{in} are higher than the ones in Egypt, Turkey, and Kuwait, and less than the recorded ones in Saudi Arabia. For the ADR, while the minimum level in the current study is higher than the level in Turkey [17] , Egypt [18], Sudan [29] , and Kuwait [28] and is less than the level recorded in Saudi Arabia [25] China [26] and Sri Lanka [27]. Finely, the minimum limit of AED is higher than the ones in Egypt [18], Turkey [17], Saudi Arabia [25], Kuwait [28]and Sudan [29].

Table 6. Comparison of radiation hazard indices of sand samples with different areas of oil and gas societies around the world.

Country	Rang	Ra_{eq} Bq.Kg^{-1}	I_{γ}	H_{ex}	H_{in}	ADR nGy.h^{-1}	AED (µSv.y^{-1})	Ref.
Yemen	Min	55.84	0.47	0.15	0.17	29.40	36.06	(this study)
	Max	116.38	0.91	0.33	0.38	57.50	70.52	
Egypt	Min	25.50	0.18	0.06	0.07	11.49	10	(18)
	Max	73.40	0.59	0.21	0.26	37.71	50	
Turkey	Min	16.50	-	0.04	0.06	7.80	9.60	(17)
	Max	106.80	-	0.29	0.35	51.70	56.20	
Saudi Arabia	Min	64.40	-	0.17	0.22	31.30	19	(25)
	Max	111.80	-	0.31	0.39	55.61	34	
China	Min	134.80	-	0.36	-	64.50	79	(26)
	Max	151.40	-	0.41	-	74.60	91	
Sri Lanka	Min	-	-	-	-	-	42.07	(27)
	Max	-	-	-	-	-	51.86	
Kuwait	Min	6.7	0.03	0.02	0.03	3.50	4.30	(28)
	Max	75	0.27	0.20	0.35	35.60	43.60	
Sudan	Min	-	-	-	-	23.42	20	(29)
	Max	-	-	-	-	75.46	90	

and less than the ones in China and Sri Lanka [27]. The maximum limit is higher than the values in Egypt, Turkey, Saudi Arabia, Sri Lanka, and Kuwait, and less than the ones recorded in Sudan and China.

In general, by examining the results in tables 3, 4 and 5 and figures 2 and 3, findings revealed that the listed values are below the global mean levels of risks, indicating that the probability of radiation hazards is very low in the area under observation. However, variation is observed in the concentration of radiation in this area. A higher concentration of radioactivity was observed in the southeast of Ma'rib Governorate, where, waste petroleum is disposed off. It can be noted from the above-discussion that the highest values are in the southeastern sites that extends to the centre of the Governorate due to the presence of petroleum waste dumping areas as well as performing the oil and gas production processes in these regions. The higher concentration of radioactivity in these sites may be attributed to the leakage of radionuclides resulting from the oil and gas industry. Another justification can be attributed to the geological formation of this studied area. In general, currently there are no any significant radiological hazards to the population living in this area and the surrounding environment.

CONCLUSION

Based on the measured values of radioactivity concentrations in collected sand samples, most of the radiological parameters including radioactive hazard coefficients for radium equivalents, the efficacy concentration factor, the internal and external risk coefficient, the absorbed dose, and the effective dose were found to be within the permissible limit of the global values, and therefore, poses no radiation hazards for the inhabitants of this area.

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