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RESEARCH ARTICLE

ASSESSMENT OF NATURAL RADIOACTIVITY LEVEL AND ASSOCIATED RADIOLOGICAL HAZARDS IN MARINE SEDIMENT SAMPLES COLLECTED FROM ABYAN BEACH, GULF OF ADEN, YEMEN

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Abstract

Twenty three marine sediment samples taken from the side beach from the Abyan beach, Aden Gulf, Yemen to measuring the activity concentration of terrestrial radionuclides radium-226, thorium-232 and potassium-40 and its associated hazard indices using gamma spectrometer with High-Purity Germanium HPGe detector. The average activity concentration of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}k in marine sediments samples under investigation were 16.25± 0.63Bqkg^{-1}, for Ra-226, 23.80± 1.46Bqkg^{-1} for Th-232 and 518.54±44.61Bqkg^{-1} for K-40 respectively. The radiation hazard indices which resulting from the presence of natural radionuclides in marine sediment samples were calculated and the obtained results indicate that the average value of radium equivalent activity was 90.21Bqkg^{-1}. The average value of External hazard index H_{ex} was 0.243 and the average values of internal hazard index H_{in} was 0.287. The average value of outdoor absorbed dose rate $Dout$ was 43.66nGyh^{-1} and indoor absorbed dose rate D_{in} was 83.13nGyh^{-1}. The average values of annual outdoor effective dose AED_{out} was 0.053mSvy^{-1}and the annual indoor effective dose AED_{in} was 0.407mSvy^{-1}. The average values of the annual gonadal dose equivalent $AGDE$ were 312.52µSvy^{-1}. While the average values of outdoor excess life-time cancer risk $ELCR_{out}$ was 0.187×10^{-3} and the indoor excess life-time cancer risk $ELCR_{in}$ was 1.427×10^{-3}. They are less than worldwide limits.

Keywords: Natural radioactivity, Abyan beach, Radiation hazards, Marine sediments, HPGe detector.

1. Introduction

Human environment is naturally radioactive, and human beings are exposed to radiation arising from natural sources, including cosmic and terrestrial origin, in addition to artificial radioactivity from fallout in nuclear testing and medical applications. Natural sources contribute approximately 80% of the environmental radiation [1]. Radioactivity naturally exists in the environment in different conditions such as soil, underground water, marine sediment, and biota. Radioactivity enters the marine environment through different pathways, including via river and rainwater transport into the sea; however, this is often due to nuclear waste disposal, which is discharged from nuclear power plants as well as from medical, industrial, research, and educational uses of radionuclides [2]. The activity concentration levels of terrestrial radioactive nuclides which found in air, soil, underground water, marine sediment, and biota and other component of the environment are depending on the properties of the geological, geochemical and geographical of the region under studied and appear at different rates of the world [3, 4]. There are few areas in the world such as Brazil, China, India, Austria, France and Iran where the background radiation levels were found to be high; varying over an order of magnitude depending upon the site-specific terrestrial radioactivity. [5, 6, 7]. Radiation and radioactivity in the environment have natural and man-made sources. Exposure to natural radiation represents the most significant part of the total exposure to radiation in the environment [8, 9, 10]. Only natural radionuclides with half-lives comparable with the age of the earth or their corresponding decay products existing in terrestrial material such as ^{232}Th, ^{238}U, ^{235}U, ^{226}Ra, ^{228}Ra and ^{40}K are of great interest. The levels of these radionuclides are relatively distributed in soil based on the nature of its geological formations [10, 11]. The uptake of radionuclides by marine sediments depends on their physical and chemical properties. The radionuclides distribution in marine sediments provides essential information concerning sediments movement and accumulation that provide a strong signal indicating sediment origin [12, 13]. Assessing radiation exposure among humans requires a better understanding of the radionuclide's behavior in pertinent environments. Thus, the primary aims of nearly all marine radioactivity studies have been to form a scientific foundation upon which to determine the radiological risk of radioisotopes in marine environments. This is an enormously important issue that is in alignment with the present radiation protection Standards [14, 15, 16].

An attempt is made in this paper to determine the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in marine sediment samples collected from Abian beach, Aden Gulf, Yemen using high purity germanium (HPGe) detector and to compute the total absorbed gamma-dose rate in air due to the presence of ^{238}U series, ^{232}Th series and ^{40}K in the samples. It is necessary to estimate the doses received and then compare such data with the nearest relevant data for reference organisms to evaluate the likely radiation effects for such organisms in an environmental context [17]. The aim of the present work to provides database about radium-226, thorium-232 and potassium-40 concentration in marine sediments of Abyan beach, Aden Gulf, Yemen. This data can be used as a reference data for future studies and it may be useful for complete radioactivity mapping for Yemen republic.

2. Materials and Methods

2.1. Sampling and samples preparation:

Twenty three sand beach sediment samples have been collected from predetermined undisturbed areas alongside the coast of Abyan beach, Aden Gulf, Yemen during low-tide (figure.1). At each of the sample sites, a sampling area of 1m^2 was considered, where five wet samples were taken, each weighing about 1kg. Four samples were taken from the corners of the site and the fifth was from the center. The sediment samples were taken at depth of 5cm from the surface; the samples were collected using Grab sample equipment. Then separated from the contamination materials and air-dried at room temperature for a week, then dried to 110^{o}C, milled and sieved through 0.2 mm sieve. The dried samples were put inside cylindrical can. The cans were sealed, gas-tight and stored for four weeks for secular equilibrium [4, 18].

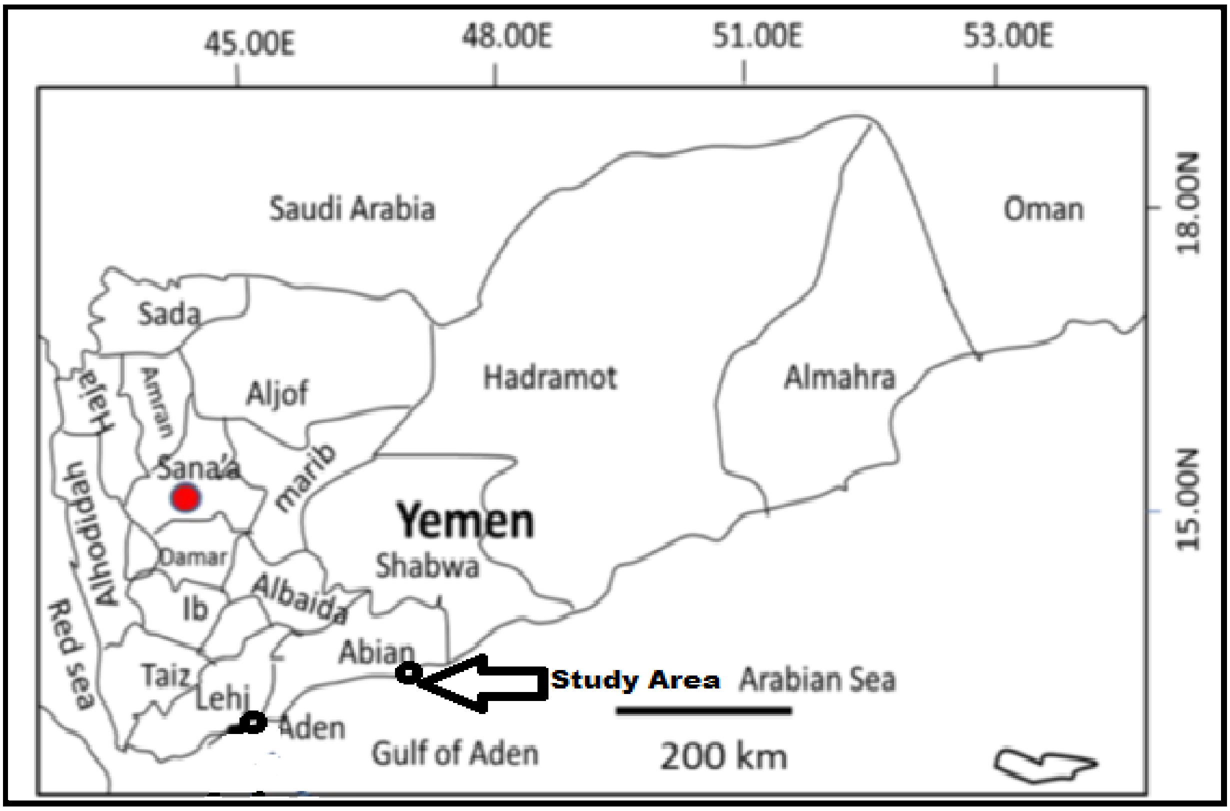

Fig. 1: Map of the study area.

2.2. Experimental Setup

The measurement of the activity concentration of the ^{238}U, ^{232}Th was by way of the daughter products. For a nuclide having more than one peak in the spectrum, the activity concentration was obtained as the weighted average activity at each peak. The emissions of ^{214}Bi (609.31, 1120.29, 1764.49keV) and ^{214}Pb (295.22, 351.93keV) were used to determine the activity of ^{238}U. The activity of ^{232}Th was estimated from the ^{212}Bi, ^{212}Pb, and ^{228}Ac radionuclide activities measured directly from their gamma-ray energy lines 727.17, 238.63, and 911.60keV, respectively. The activity concentrations of ^{40}K were determined using its only γ- ray line of peak energy 1460.82keV. Prior to sample measurement, the background was determined with an empty Marinelli beaker under identical measurement conditions as the samples. Counting time was 72, 0 0 0 s. The data acquisition, display and on-line spectrum analysis were carried out using the Genie 2000, spectroscopy software from Canberra [7]. The activity concentration (A_{Ei}) (Bq/kg) of each radionuclide in any given sample was calculated from the spectrum using the following analytical expression:

$$A_{Ei} = \frac{NP}{t_c . I_\gamma (E_\gamma) . \varepsilon (E_\gamma) . M} \quad (1)$$

Where NP is the number of count in a given peak area corrected for background peaks of a peak at energy E, $\varepsilon(E_\gamma)$ the detection efficiency at energy E, t_c is the counting life time, $I\gamma$ (E_γ) the number of gammas per disintegration of this nuclide for a transition at energy E, and M the mass in kg of the measured sample [15, 16].

3. Results and Discussion

3.1. Activity concentrations in Coastal Marine Sediment Samples

The activity concentration in (Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K for Coastal Marine sediment samples collected from the coast of Abian beach, Aden Gulf, Yemen are listed in (Table1) and shown in figure (2). The mass concentrations of Th and U were calculated from ^{238}U (assuming secular equilibrium between ^{238}U and ^{226}Ra, as well as their progenies) and from ^{232}Th (assuming secular equilibrium between ^{232}Th and ^{228}Ra). The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in Coastal Marine Sediment samples were found to vary between 9.44±0.38 to 36.30±1.41Bqkg^{-1} with average value 16.25± 0.63Bqkg^{-1}for ^{226}Ra. The lowest level was observed at sample number 23 and the highest was found at sample number 11. It is clear that the highest level of ^{226}Ra is 4-fold of the lowest level. ^{232}Th results indicated a range from 12.94±0.79 to 95.75±5.88Bqkg^{-1} with average value 23.80± 1.46Bqkg^{-1}.The lowest value was recorded at sample number 12 and the highest levels were at sample number 11. The range of ^{232}Th showed that the highest level is 7-fold of the lowest value. The difference between the sample in the west and the sample in the east could be explained by the presence of black sands deposits, which contain heavy minerals such as monazite. These sands contain, overall, two orders of magnitude more of ^{232}Th and ^{238}U decay series radionuclides [19, 12]. ^{40}K results indicated a range from 296.67±25.52Bqkg^{-1} to 747.72±64.32Bqkg^{-1} with the average value 518.54± 44.61Bqkg^{-1}. The lowest level was observed at sample number 11 and the highest was found at sample number 05. The bar diagrams distributions of radioactivity levels over the investigated samples are shown in Figure **(2)** for^{226}Ra, ^{232}Th and ^{40}K, respectively. The worldwide concentrations of the radionuclides U-238, Th-232, and K-40 have averages in marine sediment samples of 35, 30, and 400Bqkg^{-1} respectively (UNSCEAR, 1993) [2]. Our results show that the mean activity concentrations of ^{226}Ra and ^{232}Th radionuclides are lower than the worldwide concentrations according to the UNSCEAR report [2, 20]. These average values agreed well with the result obtained in earlier studies for ^{226}Ra and ^{232}Th [12]. The average activity concentrations of ^{40}K for all samples were higher than the world average value 400 Bqkg^{-1}[4]. A large variability in activity concentrations is shown among radionuclides, reflecting the geological and morphological characteristics of the collected sediments, as well as their respective radionuclide contents. A high degree of variability in the measured radioactivity was shown in the studied samples, as these samples reflect the geological characteristics of their sites of origin. Usually, the radioactivity of ^{238}U and ^{232}Th is linked with heavy minerals, while that of ^{40}K is associated with clay minerals. In Table 2, a comparison is given of the average (range) radioactivity concentrations (Bqkg^{-1}) obtained in this work versus in the literature. According to the IAEA, when the activity of the ^{238}U or ^{232}Th decay series is ≤ 1000Bqkg^{-1}and that of ^{40}K is ≤ 10,000Bqkg^{-1}, the radioactive material may not be regarded as naturally occurring and is thus exempt from regulations [8, 16].

Table 1: Activity concentration (Bq.Kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in Coastal Marine Sediment samples.

Sample Number	Coordinates		Activity concentration (Bq/ kg)		
	Latitude(N)	Longitude (E)	226Ra	232Th	40K
S 01	12°53'36.1"	44°54'32.0"	15.54±0.61	19.31±1.22	447.07±38.458
S 02	12°56'80.9"	45°06'12.9"	17.86±0.73	29.73±1.82	588.09±50.589
S 03	12°57'31.4"	45°06'31.9"	26.47±1.02	34.52±2.11	556.55±47.876
S 04	12°57' 58.9"	45°06'72.3"	15.83±0.61	15.87±0.96	725.27±62.39
S 05	12°58'03.0"	45°07'07.0"	21.63±0.84	20.89±1.28	747.72±64.32
S 06	12°53'61.9"	45°07'69.4"	30.40±1.17	37.33±2.29	632.75±54.43
S 07	12°59'08.0"	45°08'29.6"	14.65±0.56	18.59±1.14	604.01±51.959
S 08	12°59'48.7"	45°08'93.8"	14.17±0.55	16.27±0.99	658.26±56.62
S 09	12°59'71.7"	45°09'36.9"	17.84±0.69	21.20±1.29	622.86±53.58
S 10	12°59'97.6"	45°09'90.6"	11.44±0.44	13.29±0.81	584.06±50.24
S 11	13°00'37.8"	45°10'82.3"	36.30±1.41	95.75±5.88	296.67±25.52
S 12	13°00'80.2"	45°11'90.7"	10.70±0.41	12.94±0.79	478.49±41.16
S 13	13°01'17.5"	45°12'93.9"	12.15±0.49	13.55±0.82	585.13±50.33
S 14	13°01'47.8"	45°13'89.7"	12.18±0.47	17.00±1.03	485.73±41.78
S 15	13°01'78.6"	45°14'67.4"	11.89±0.46	13.61±0.83	554.15±47.67
S 16	13°01'.980"	45°15'.591"	13.07±0.51	17.65±1.08	457.33±39.34
S 17	13°02'13.4"	45°16'20.0"	11.80±0.45	14.97±0.92	533.57±45.899
S 18	13°04'63.2"	45°24'22.7"	14.24±0.55	22.45±1.37	301.96±25.97
S 19	13°04'00"	45°23'.042"	11.57±0.45	14.31±0.87	586.37±50.44
S 20	13°03'19.7"	45°22'03.1"	15.74±0.62	34.52±2.11	326.53±28.089
S 21	13°02'.506"	45°17'84.1"	13.45±0.52	20.13±1.24	349.71±30.08
S 22	13°02'42.8"	45°17'43.3"	15.43±0.59	24.10±1.48	434.70±37.39
S 23	13°02'21.7"	45°16'52.2"	9.44±0.38	19.36±1.19	369.51±31.786
Minimum			**9.44±0.38**	**12.94±0.79**	**296.67± 25.52**
Maximum			**36.30±1.41**	**95.75±5.88**	**747.72± 64.32**
Mean			**16.25± 0.63**	**23.80± 1.46**	**518.54± 45.84**

Table 2: Comparison of average (range) radioactivity concentrations (Bqkg^{-1}) with other studies.

Country	^{226}Ra	^{232}Th	^{40}K	Reference
Worldwide	35	30	400	[20]
Abian beach, Aden Gulf, Yemen	9.44-36.30	12.94-95.75	296.67-747.72	Present study
Gulf of Oman	9.3 - 24.8	10.4 - 54.9	29.0–78.7	[16]
Arab Sea Qatar	4.2–19.5	1.0–6.0	11–188	[21]
Arab Sea Kuwait	17.3–20.5	15–16.4	353– 445	[22]
Arab Sea Kuwait	18.6–21.4	14.0–17.1	351.2– 404	[23]
Saudi Arabia	4.4–19.3	5.3–58.9	324.6–1133	[24]
Red Sea, Egypt	1.92- 17.55	5.62- 28.77	123.27- 277.38	[4]
Alexandria beach, Egypt	12.6-499.18	0.65–386.2	10-122	[12]
Kuakata beach, Bangladesh	48.76 ±5.29	126.11 ±3.31	292.38 ±18.24	[6]
Rizhao beaches (China)	12	15	1079	[25]
Beaches of Aegean sea (Turkey)	290	1160	532	[26]
Sediments of Cadiz Bay (Spain)	13	451	19	[27]
Beach of Jeddah Saudi Arabia	14.22	14.00	968.19	[28]
Sediment, Saudi Arabia	18.3-37.6	7.8-25.5	202-432	[29]
Surface Sediment Yangtze Estuary	13.7–52.	26.1–71.9	392–898	[30]

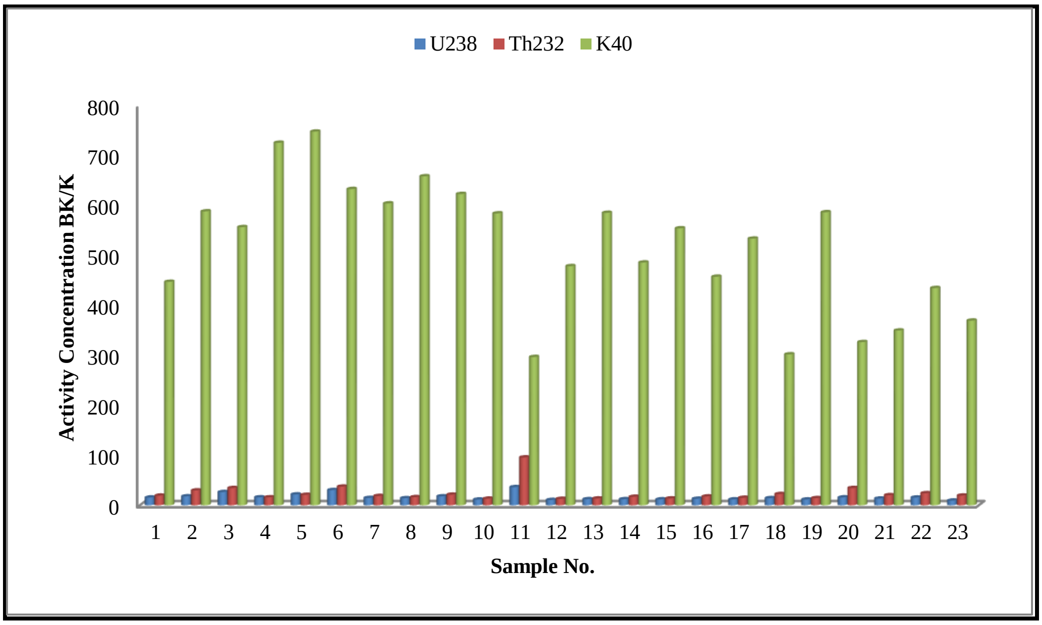

Fig.2: ^{226}Ra, ^{232}Th, and ^{40}K Activity concentration ($Bq.Kg^{-1}$) in Marine sediment sample.

3.2 Assessing Radiological Hazards

3.2.1. Radium equivalent activity (Ra_{eq})

Radium-equivalent activity (Ra_{eq}) is a single parameter that represents the collective risk of ^{226}Ra, ^{232}Th, and ^{40}K radioactivity [16, 31, 32]. This parameter can be used to assess whether external doses to the public exceed the recommended annual dose limit of 1mSv. Ra_{eq} was calculated from the next equation (2):

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

Where A_{Ra}, A_{Th}, and A_K, are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. Table 3 presented the measured radium equivalent activity Ra_{eq} in sediment samples which were ranged from 65.58to196.06$Bqkg^{-1}$with an average value 90.21$Bqkg^{-1}$. The results are lower than the recommended limit 370$Bqkg^{-1}$ reported by UNSCEAR (1988,2000) [1, 33]. The behavior of radium equivalent activity Ra_{eq} is shown in Figure 3.

3.2.2. External Hazard Index (H_{ex})

The external radiation exposure due to natural radioactivity is defined in terms of the external hazard index (H_{ex}), calculated as follows **[16, 2, 31]**:

$$H_{ex} = (A_{Ra}/370 + A_{Th}/259 + A_K/4810) \leq 1 \quad (3)$$

Where A_{Ra}, A_{Th}, and A_k are the specific activities ($Bqkg^{-1}$) of ^{226}Ra, ^{232}Th, and ^{40}K, respectively in the studied samples. To comply with the requirements of the 1mSv annual dose limit for the public, H_{ex} should be <1, as shown above [20]. As seen in Table 3, the H_{ex} values ranged from 0.177 to 0.529 with an average value (0.24)**.** These results ensure that the public's exposure to the environmental radioactivity of ^{226}Ra, ^{232}Th, and ^{40}K radionuclides in beach sediment remain within acceptable limits.

3.2.3. Internal hazards index (H_{in})

In addition to the external radiation hazard they pose, radon and its short-lived daughters are also hazardous to the respiratory organs. The internal exposure caused by radon and its daughter products is quantified by the internal hazard index H_{in}, which has been calculated as follows [16, 2, 31]:

$$H_{in} = (A_{Ra}/185 + A_{Th}/259 + A_K/4810) \leq 1 \quad (4)$$

The values of internal hazard index H_{in} As seen in Table 3 ranged from 0.203 to 0.627 with an average value 0.29, which is lower than the worldwide limit ≤1 recommended by UNSCEAR (2000) [33]. The behavior of external hazard index (H_{ex}) and internal hazard index H_{in} is shown in Figure 4.

3.3. Absorbed dose rate

Absorbed dose (D) assess the energy which stored in a medium due to the ionizing radiation emitted from natural occurring radionuclides ^{238}U, ^{232}Th, and ^{40}K and measured in SI units as joules per kilogram Gray (Gy). It is calculated based on guide lines provided by UNSCEAR 2000 [33]. To convert the activity concentration of ^{238}U, ^{232}Th, and ^{40}K radionuclides into doses in ($nGyh^{-1} per Bqkg^{-1}$), UNSCEAR (1988) has given the dose conversion factors as 0.427, 0.662 and 0.043 respectively [1]. Using these factors, the outdoor absorbed dose rate is calculated using the following equation [2]**:**

$$D_{out}\,(nGy.h^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.042A_K \quad (5)$$

The indoor gamma ray dose imparted by of ^{238}U, ^{232}Th, and ^{40}K radionuclides present indoor can be calculated by converting the absorbed dose rate to effective dose by using the conversion factors 0.92, 1.1 and 0.081$nGyh^{-1} per Bqkg^{-1}$ respectively. By using these factors following, the following equation is used to calculate the indoor dose rate, given by UC European Commission (1999) [34]:

$$D_{in}\ (nGy.\text{h}^{-1}) = 0.92A_U + 1.1A_{Th} + 0.081A_K \qquad (6)$$

Table 3 shows the calculated outdoor absorbed dose D_{out} due to the presence of ^{238}U, ^{232}Th, and ^{40}K in the marine sediments of Abian beach, that ranged from 31.57 to 87.06$nGy\text{h}^{-1}$ with an average value of 43.66$nGy\text{h}^{-1}$ which is lower than the worldwide limit of 59$nGy\text{h}^{-1}$ as presented by UNSCEAR (2000) [33]. The values of indoor absorbed dose D_{in} calculated during present study range from 59.91 to 162.75$nGy\text{h}^{-1}$ with an average of 83.13$nGy\text{h}^{-1}$, Our results are higher than the doses reported in Gulf of Oman (49.26nGy^{-1}) [16]. Our results are within the worldwide limit of 84$nGy\text{h}^{-1}$ as recommended by UNSCEAR (2000) [33]. The behavior of indoor and outdoor absorbed dose in samples is shown in Figure 5.

Table 3: Radium-equivalent activity, absorbed dose rates, effective rates, excessive cancer risk, annual gonadal dose and external hazard index (H_{ex}) associated with the radioactivity in Coastal Marine Sediment samples.

Samples code	Ra_{eq} (Bq/kg)	Dout (nGy/h)	Din (nGy/h)	AEDEout (μSv/y)	AEDEin (mSv/y)	AGDE (μSv/y)	H_{ex}	H_{in}	$ELCR_{in}$	$ELCR_{out}$
S 01	77.58	37.62	71.75	0.046	0.352	269.11	0.209	0.251	1.23	0.161
S 02	105.66	50.91	96.77	0.062	0.475	364.13	0.285	0.333	1.66	0.218
S 03	118.68	56.45	107.39	0.069	0.527	400.82	0.320	0.392	1.84	0.242
S 04	94.37	47.36	90.76	0.058	0.445	342.98	0.255	0.297	1.56	0.203
S 05	109.08	54.02	103.44	0.066	0.507	388.95	0.294	0.353	1.78	0.232
S 06	132.49	63.16	120.28	0.077	0.590	448.65	0.358	0.439	2.06	0.271
S 07	87.75	43.37	82.85	0.053	0.406	312.64	0.237	0.276	1.42	0.186
S 08	88.12	44.02	84.25	0.053	0.413	318.48	0.238	0.276	1.45	0.189
S 09	96.12	47.21	90.19	0.058	0.442	339.33	0.259	0.308	1.55	0.203
S 10	75.42	37.84	72.46	0.046	0.355	274.31	0.204	0.234	1.24	0.162
S 11	196.06	87.06	162.75	0.107	0.798	605.55	0.529	0.627	2.79	0.374
S 12	66.05	32.86	62.84	0.040	0.308	237.40	0.178	0.207	1.08	0.141
S 13	76.58	38.37	73.48	0.047	0.360	277.92	0.207	0.239	1.26	0.165
S 14	73.89	36.29	69.25	0.044	0.339	261.23	0.199	0.232	1.19	0.156
S 15	74.023	36.99	70.79	0.045	0.347	267.64	0.199	0.232	1.21	0.159
S 16	73.53	35.91	68.48	0.044	0.336	257.77	0.198	0.234	1.17	0.154
S 17	74.29	36.90	70.54	0.045	0.346	266.57	0.201	0.232	1.21	0.158
S 18	69.59	32.82	62.26	0.040	0.305	232.66	0.188	0.226	1.07	0.141
S 19	77.18	38.62	73.88	0.047	0.362	279.69	0.208	0.239	1.27	0.166
S 20	90.25	41.84	78.90	0.051	0.387	295.47	0.244	0.286	1.35	0.179
S 21	69.17	33.06	62.85	0.040	0.308	235.54	0.187	0.223	1.08	0.142
S 22	83.36	39.94	75.91	0.049	0.372	284.91	0.225	0.267	1.30	0.171
S 23	65.58	31.57	59.91	0.039	0.294	226.13	0.177	0.203	1.029	0.135
Worldwide	370	59	84	0.07	0.45	100	≤ 1	≤ 1	1.16	1.45
Min.	65.58	31.57	59.91	0.039	0.294	226.13	0.177	0.203	1.029	0.135
Max.	196.06	87.06	162.75	0.107	0.798	605.55	0.529	0.627	2.79	0.374
Mean	90.21	43.66	83.13	0.053	0.407	312.52	0.243	0.287	1.427	0.187

Ra_{eq} is the radium equivalent activity; D_{in} and D_{out} are the indoor and outdoor air absorbed, respectively.

AED_{Total} is the total effective doses due to internal and external radiation exposure. ECR, excessive cancer risk.

AGD (mGy.y^{-1}), annual gonadal dose and H_{ex} is the external hazard index.

3.4. Annual effective dose equivalent ($AEDE$)

The outdoor annual effective dose equivalent ($AEDE_{out}$) was estimated from outdoor absorbed dose in air to convert it to effective dose. While the indoor annual effective dose equivalent ($AEDE_{in}$) is estimated from indoor absorbed dose in air to convert it to the effective dose. UNSCEAR (2000) [33] reported the value 0.7$SvGy^{-1}$ as conversion coefficient from absorbed dose in the air to the effective dose received by adults. While 0.2 and 0.8 represent the outdoor and indoor occupancy factors respectively. The annual indoor and outdoor effective dose rate in $mSvy^{-1}$ is given by the following formulas respectively as reported by UNSCEAR (2000) [33]**:**

$$AEDE\ (mSvy^{-1}) = D\ (nGyh^{-1}) \times 8760h \times 0.8 \times 0.7\ SvGy^{-1} \times 10^{-6} \quad (7)$$

$$AEDE\ (mSvy^{-1}) = D\ (nGyh^{-1}) \times 8760\ h \times 0.2 \times 0.7\ SvGy^{-1} \times 10^{-6} \quad (8)$$

The values of outdoor annual effective dose equivalent $AEDE_{out}$ for Abyen beach sediments ranges from 0.039 to 0.107$mSvy^{-1}$with an average of 0.053$mSvy^{-1}$ which is lower than the worldwide average of 0.07$mSvy^{-1}$.

The indoor annual effective dose equivalent $AEDE_{in}$ calculated with a range from 0.29 to 0.798$mSvy^{-1}$with an average value 0.41$mSvy^{-1}$which is same as the worldwide limit of 0.41$mSvy^{-1}$reported by UNSCEAR (2000) [33]. The total average annual effective dose equivalent was estimated to be 0.44$mSvy^{-1}$which is within the worldwide limit of 0.48mSv/y as predicted by UNSCEAR (2000) [34]. Spatial distribution of total annual effective dose equivalent in studied area is shown in Figure 6. From Table 3 it can be seen that the estimated values of annual effective dose obtained in this study is higher than the value reported in Gulf of Oman (0. 27$mSvy^{-1}$) [16].

3.5. Annual Gonadal Dose Equivalent (AGDE)

The United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (1988) [1] has been interested active bone marrow and bone surface cells as organs. Therefore, the annual gonadal dose equivalent ($AGDE$) due to the specific activities of ^{226}Ra, ^{232}Th, and ^{40}K in studied samples was estimated using the following equation: [33].

$$AGDE\ (\mu Sv/y) = 3.09A_U + 4.18A_{Th} + 0.314A_K \quad (9)$$

The obtained values of $AGDE$ are listed in Table 3. The values of $AGDE$ varied from 226.13 to 605.55$\mu Svy^{-1}$and the average value was found to be 312.52μSvy^{-1}. The average value of AGDE was found to be 181.1μSvy^{-1}in Gulf of Oman [16]. Also, the average value of $AGDE$ was found to be 2850 μSvy^{-1}in Kerala, India [35]. These two values of $AGDE$ are higher than our result in Kerala, India and lower than our result in Gulf of Oman. The obtained AGDE value for marine beach sediments in Abian beach is higher than the worldwide limit of 300μSvy^{-1} according to UNSCEAR reports [2]. The behavior of $AGDE$ in samples is shown in Figure 7.

3.6. Life-time cancer risk ($ELCR$)

The excess life-time cancer risk ($ELCR$) was estimated from annual effective dose equivalent using the equation [36, 37]**:**

$$ELCR_{out} = AEDE_{out} \times DL \times RF \quad (10)$$

$$ELCR_{in} = AEDE_{in} \times DL \times RF \quad (11)$$

Where D_L, and R_F are the duration of life (70 years), and risk factor (0.05/Sv), respectively. Defined the risk factor as fatal cancer risk per Sievert is assigned a value of 0.05 by ICRP (2012) [37] for the public for random effects, for low-level radiations.

The excess lifetime cancer risk $ELCR$ for outdoor exposure calculated for sediment, given in Table 3 varied between 0.135×10^{-3} and 0.374×10^{-3} with average value of 0.187×10^{-3}. This value was found to be less than the limit of 0.29×10^{-3} set by UNSCEAR (2000) [33].

For indoor exposure it is varied from 1.029×10^{-3} to 2.79×10^{-3} with an average of 1.427×10^{-3}. It is higher than the limit 1.16×10^{-3} [36]. The total $ELCR$ ranges from 1.16×10^{-3} to 3.17×10^{-3} with an average value of 1.61×10^{-3}. It clear that the ELCR for marine beach sediments in Abian beach is higher than the worldwide limit of 1.45×10^{-3} [33]. The behavior of $ELCR$ in samples is shown in Figure 8.

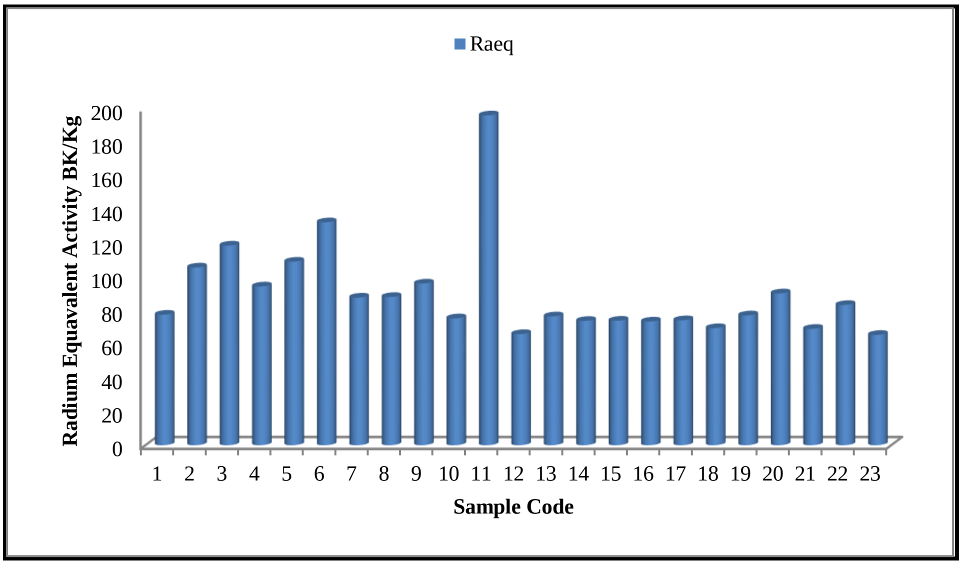

Fig. 3: Radium Equivalent Activity of sediment sample

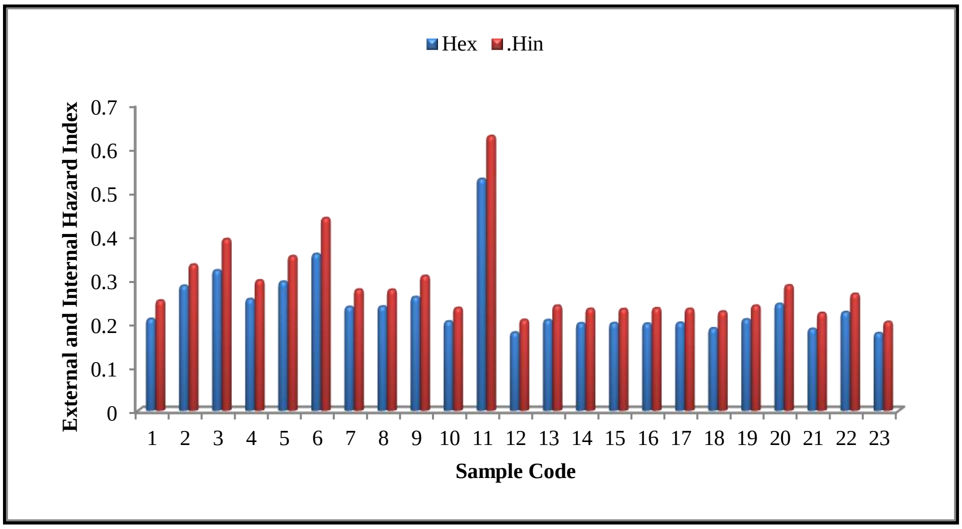

Fig. 4: Hazard Index of sediment samples.

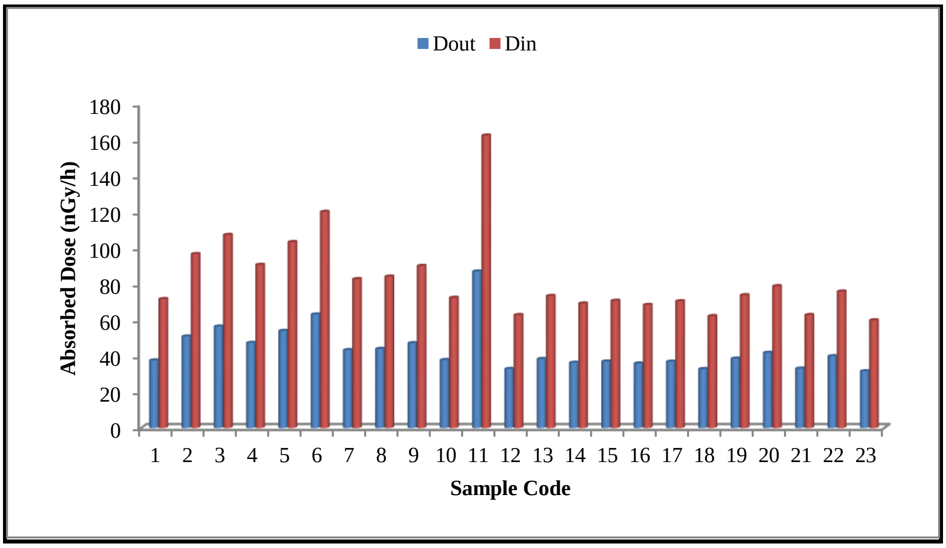

Fig. 5: Absorbed Dose of sediment samples.

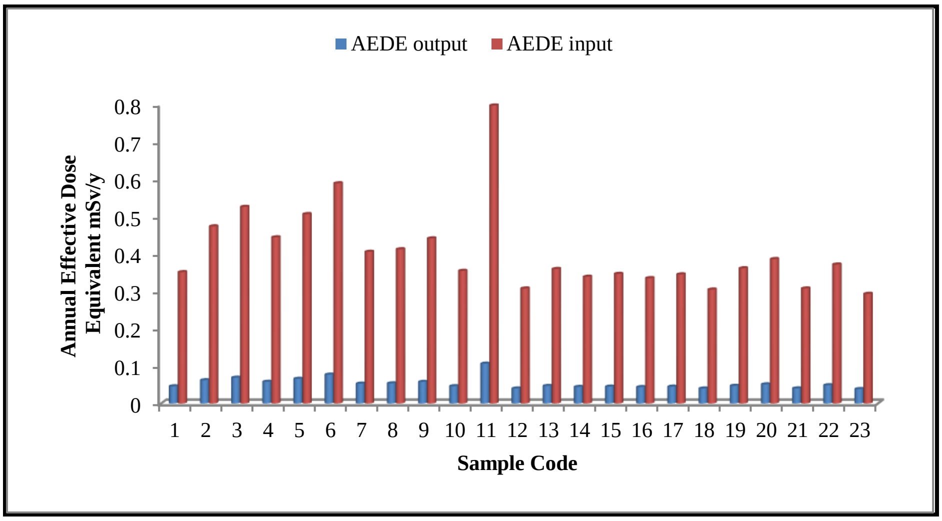

Fig. 6: Annual Effective Dose of sediment samples.

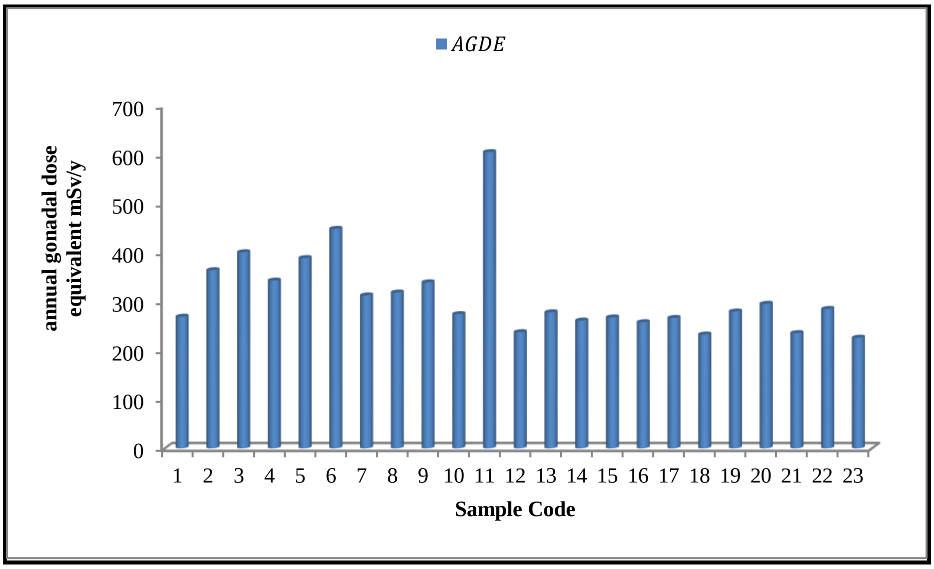

Fig. 7: Annual gonadal dose equivalent of sediment samples.

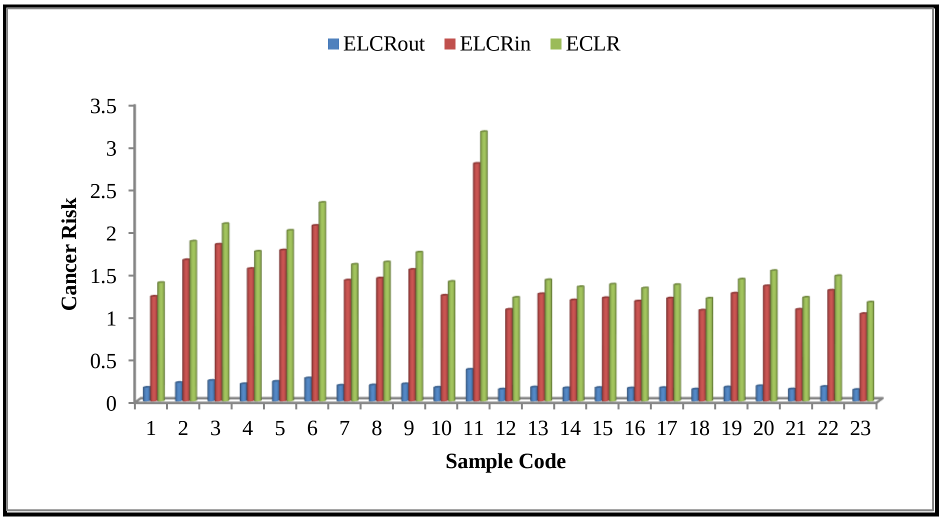

Fig. 8: Excess Lifetime Cancer Risk of Sediment Samples.

4. Conclusions

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the studied samples are found to be normal and below the average global values. The average radium equivalent activity (R_{eq}) and external hazard (H_{ex}) indices were less than the world average values. The calculated average absorbed dose rate and estimated, annual effective dose, annual gonadal dose equivalent ($AGDE$), excess life-time cancer risk ($ELCR$) were found lower than the worldwide average values for Marine sediments samples. By reference to the values of radiation hazard indices for all marine sediments samples collected from Coastal Marine of Abian beach, Aden Gulf, Yemen. Therefore, the probability of the radiological impact on the inhabitants/public living in this area will be insignificant. It is not also hazardous for tourist because they stay for short period in the concerning area. The radioactivity levels in sediments are a source of radiation exposure for marine organisms. Regular monitoring of radioactivity levels is vital for radiation risk confinement. The results provide important baseline data to which future radioactivity levels in marine environments can be compared. Considering the fact that oceans and seas form the ultimate sink of contaminants, including radioactivity, future research initiatives that study radioactivity levels in marine environments and assess associated radiological hazards to the population are of utmost importance in order to ensure protection of the marine environment. Such a project should also consider investigating radioactivity from artificial radionuclides.

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مقالة بحثية

تقدير مستوى الاشعاع الطبيعي والمخاطر المصاحبة للاشعاع لعينات رملية من بقايا البحر جمعت من شاطىء ساحل ابين على خليج عدن - اليمن

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المُلخّص

تمَّ تجميع 23 عينه بقايا بحرية من ساحل ابين على شاطئ خليج عدن لقياس تركيز الراديوم-226، الثوريوم -232 والبوتاسيوم -40 ومعاملات الاخطار الناتجة عنها بأستخدام كاشف الجرمانيوم عالي النقاوة HPGe. اظهرت النتائج ان اعلى تركيز لفعالية نويدة الراديوم-226 وجدت في العينة S11 والذي تساوي (36.300±1.41Bq/kg) بينما اقل قيمة وجدت في العينة S23 والذي تساوي (9.44±0.38Bq/kg) بمعدل تركيزيساوي (16.25±0.53Bq/kg). بينما وجدت اعلى تركيزلفعالية نويدة الثوريوم -232المشعة طبيعيا"في العينة S11 والذي تساوي (95.75±5.88Bq/kg) واقل قيمة وجدت في العينة S12 والذي تساوي (12.94±0.79Bq/kg) بمعدل تركيزيساوي (23.80±1.46Bq/kg). اما اعلى تركيز لفعالية نويدة البوتاسيوم -40 فقد وجدت في العينةS5 والتي تساوي (747.72±64.32Bq/kg) واقل قيمة وجدت في العينة S11 والذي تساوي (296.67±25.52Bq/kg) بمعدل تركيزيساوي (518.54±45.84Bq/kg). تم حساب معاملات الاخطار الاشعاعية الناتجة عن تواجد هذه الانوية الطبيعية في عينات البقايا البحرية المقاسة. اظهرت النتائج ان فعالية المعامل الراديومي (Ra_{eq}) تقع في المدى (65.58to196.06Bq/kg) بمعدل يساوي (90.21Bq/kg)، معامل الخطورة الخارجي (H_{ex}) يقع في المدى (0.177 to 0.529) بمعدل يساوي 0.243، معامل الخطورة الداخلي (H_{in}) يقع في المدى (0.203 to 0.627) بمعدل يساوي 0.287. حسبت معدل الجرعة الممتصة الخارجي D_{out} ومعدل الجرعة الممتصة الداخلي (D_{in}) ووجدت انها تقع في المدى (31.57 to $87.06nGyh^{-1}$)، (59.91 to $162.75nGyh^{-1}$) بمعدل يساوي $43.66nGyh^{-1}$, $83.13nGyh^{-1}$ على التوالي. حسبت الجرعة السنوية المؤثرة الخارجية (AED_{out}) والداخلية (AED_{in}) ووجدت انها تقع في المدى (0.294 to $0.798mSvh^{-1}$), (0.039 to $0.107mSvh^{-1}$) بمعدل يساوي $0.053mSvh^{-1}$ و $0.407mSvh^{-1}$ على التوالي. حسبت قيم الجرعة المكافئة السنوية للغدة التناسلية AGDE ووجدت انها تقع في المدى (226.13 to $605.55\mu Svh^{-1}$) بمعدل يساوي$312.52\ \mu Svh^{-1}$.بينما حسبت قيمة كل من excess life-time cancer risk ($ELCR_{out}$) الخارجي وكذلك excess life-time cancer risk ($ELCR_{in}$) الداخلي ووجدت انها تقع في المدى (0.135×10^{-3} to 0.374×10^{-3})، (1.029×10^{-3} to 2.79×10^{-3}) بمعدل يساوي (0.187×10^{-3})، (1.427×10^{-3}) على التوالي. جميع النتائج التي حصلنا عليها للعينات قيد الدراسة اقل من القيمة العليا المسموح بها والموصى بها من The World Health Organization and EU Council وان الاشعاعات الناتجة عن النويدات الطبيعية لاتشكل خطورة على الحياة البشرية.

الكلمات المفتاحية: النشاط الاشعاعي الطبيعي، ساحل ابين، اخطار الاشعاعات الطبيعية، البقايا البحرية، كاشف الجرمانيوم عالي النقاوة.

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