ISSN : 0974 - 7451 Volume 8 Issue 7

Environmental Science

An Indian Journal

Current Research Paper

ESAIJ, 8(7), 2013 [268-273]

Measurement of natural radioactivity in beach sediments from Aden coast on gulf of Aden, south of Yemen

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ABSTRACT

The distribution of natural gamma emitting ^{238}U, ^{232}Th and ^{40}K radionuclides in beach sediments along Aden coast on Gulf of Aden, South of Yemen has been carried out using a NaI(Tl) gamma ray spectrometric technique. The mean activity concentrations of measured radionuclides were compared with other literature values. The absorbed dose rate, annual effective dose equivalent, external hazard index and representative level index were calculated and compared with internationally recommended values.

KEYWORDS

Radionuclides;
Absorbed dose rate;
Hazard indices;
Epresentative level index.

INTRODUCTION

The naturally occurring radionuclides are relatively and uniformly distributed in the seas and the oceans. Human activities like mining and milling of mineral ores, ore processing and enrichment, nuclear fuel fabrication and handling of the fuel cycle tail end products cause release of additional amounts of natural radionuclides into the environment. Also, the discharge into the sea of low level waste from nuclear industry has become a source of contamination in the marine coastal environment of countries possessing nuclear power plants and nuclear reprocessing plants[1].

Most of the radioactivity deposited on surface sediments is washed by rains and drained through rivers to the oceans. Part of the ground deposited activity is absorbed in the soils and percolates with the underground waters to the oceans. Radionuclides reaching the ocean become part of the marine ecosystem (water, sediments, and biota) and may transfer through seawater-sediment-biota interface to human beings[2]. Accumulation of such substances in the marine costal environment raises many problems concerning safety of biotic life, food chain and ultimately humans. To address these problems, assessment of radioactivity concentration in the marine environment is essential. It is necessary to quantify the distribution of radionuclides in the main marine constituents (sea water, sea sediments and marine organisms) and to assess radiological impacts of the detected radionuclides on human health. Beach sediments are mineral deposits formed through weathering and erosion of either igneous or metamorphic rocks. Among the rock constituent minerals are some natural radionuclides that contribute to ionizing radiation exposure on Earth. Natural radioactivity in soils comes from U and Th series and natural K.

The study of the distribution of primordial radionuclides allows the understanding of the radiological implication of these elements due to the gamma-ray exposure of the body and irradiation of lung tissue from inhalation of radon and its daughters[11]. During the last few decades, the coastal environment of Aden coast Gulf of Aden, South of Yemen has experienced intense developments in industry, tourism, transport, urbanization and aquaculture.

This paper reports the activity concentrations of natural radionuclides ^{238}U, ^{232}Th and ^{40}K, for beach sediments of Aden coast on Gulf of Aden, South of Yemen. The objective of this paper is to evaluate the radiological hazards due to natural radioactivity associated with beach sediments by calculating the absorbed dose rate, annual effective dose rate, representative level index and external hazard index.

MATERIALS AND METHODS

This study took place in Aden coast, South of Yemen is on Gulf of Aden (figure 1). The total study area spread over from Kawa (Lat: 12º 44' 472"N; Long 44º 28'367"E) to Alalam beach (Lat: 12º 50' 759"N; Long 45º04'452"E), which covers an area about 150km. The tidal range is 1.2-1.5m for spring tides and 0.3-0.6m for neap tides

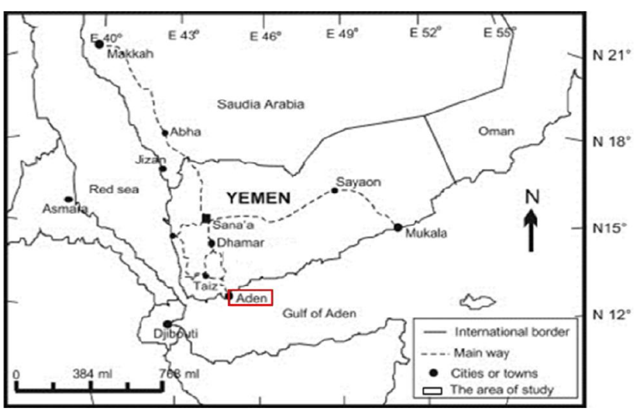

Figure 1 : Geographic location of Aden coast gulf of Aden, south of Yemen where the beach sediment samples were collected

Sample collection and preparation

Beach sediment samples were collected during January 2012. The total study area covers about 150km, from which at the distance of 2-3km interval, 44 sampling locations [S_1-S_{44}] are selected. The exact position of each sampling site was recorded using Hand held GARMIN GPS (Global Positioning System, Model no 12).The samples were collected from 10-20m away from the high tide, when it makes towards the road side. Five samples were collected from each site covering an area of one meter square, at a depth of 5cm and packed in plastic pouches.

The collected samples were dried in an oven at 100-110ºC for about 24h and sieved through a 2-mm mesh-size sieve to remove stone, pebbles and other macro-impurities. The homogenized sample was placed in a 400g airtight PVC container. The inner lid was placed in and closed tightly with outer cap. The container was sealed hermetically and externally using cellophane tape and kept aside for about a month to ensure equilibrium between Ra and its daughter products before being taken for gamma ray spectrometric analysis[8].

Gamma spectroscopic analysis

To estimate the activity levels of the ^{238}U, ^{232}Th and ^{40}K in the samples, a gamma ray spectrometer in Environmental Radioactivity Measurements Laboratory (ERML), physics department, Faculty of Science, University of south valley, Qena. was used in the present investigations. NaI(Tl) crystal detector of size 3" X 3" along with a 8K multi channel analyzer was used to record the gamma spectra.

The energy calibration of the spectrometer was performed using the 1-l Marinelli calibration sources, which contained well-known standard sources (^{137}Cs, ^{60}Co, ^{57}Co, and ^{241}Am).

The absolute efficiency of the detector was determined accurately to evaluate the radionuclide concentrations precisely. This was undertaken using multinuclide standard sources distributed in a sand matrix to be homoconditioned with the investigated soil samples. These standards were obtained from Radioactivity Measurements Laboratory (ERML), physics department, Faculty of Science, University of south valley, Qena. With the counting time of 10,000 seconds for each sample, the below detectable limit (BDL) limits were 21.2Bqkg^{-1} for ^{40}K, 5.5 Bqkg^{-1}for ^{238}U and ^{232}Th.

To determine the radioactivity concentration in the soil samples, each sample was placed on the NaI(Tl) detector and counted for the same counting time (12 h). It was found that the detected gamma lines belong to the naturally occurring series radionuclides and a non-series natural radionuclide ^{40}K.

Calculation of elemental concentration

Count rates for each detected photo peak and activity for each of the detected nuclides are calculated. The specific activity (in Bq.kg-1), A_{Ei} of a nuclide i. and for a peak at energy E, is given by:

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

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 lifetime, $I_\gamma(E_\gamma)$ 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.

Under the assumption that secular equilibrium was reached between ^{232}Th and ^{238}U and their decay products, the γ-ray transitions to measure the concentration of the assigned nuclides in the series are as follows:

(a) ^{214}Bi (609.31, 1120.3 and 1764.49 keV), ^{214}Pb (295.22 and 351.93 keV) for uranium-238.

(b) ^{208}Tl (583.19 and 2614.53 keV), ^{212}Pb (238.63Kev), ^{228}Ac (911.20keV) for the thorium series

(c) ^{40}K (1460.83 keV) for potassium.

Calculation of radiological effects

Dose rate calculation

The absorbed dose rate was calculated from the measured activities of ^{238}U, ^{232}Th and ^{40}K in the surface sediment samples using the below formula[6].

$$D\ (nGy\ h^{-1}) = 0.462\ C_U + 0.604 C_{Th} + 0.042 C_K \quad (2)$$

Where D is the absorbed dose rate (nGy h^{-1}). $C_U$and C_K are the activity concentrations (Bqkg^{-1}) of ^{238}U, ^{232}Th and ^{40}K respectively.

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose to effective dose, 0.7SvGy^{-1} and outdoor occupancy factor of 0.2 proposed by UNSCEAR, 2000 were used. The effective dose rate in units of mSv y^{-1} was calculated by the following formula

$$\text{Effective dose rate } (m\,Sv\,y^{-1}) = D\ (nGy\ h^{-1}) \times 8760\ h \times 0.2 \times 0.7\ SvGy^{-1} \times 10^{-6} \quad (3)$$

Calculation of hazard indexes

The external hazard index, H_{ex}, is defined as.

$$H_{ex} = (C_U/370 + C_{Th}/259 + C_K/4810) \le 1 \quad (4)$$

An additional hazard index so called representative level index is calculated by using the formula[4].

$$I_{dr} = (C_U/150 + C_{Th}/100 + C_K/1500) \quad (5)$$

Where C_U, C_{Th} and C_K are the specific activities (Bqkg^{-1}) of ^{238}U, ^{232}Th and ^{40}K, respectively. The value of these indexes must be less than unity in order to keep the radiation hazard insignificant.

RESULTS AND DISCUSSION

The results of analysis of activity concentration of ^{238}U, ^{232}Th and ^{40}K radionuclides in beach sediment samples for different locations of the study area are presented in TABLE 1. Activity is reported in Bqkg^{-1} on the basis of the sediment's dry weight. The measured activity concentrations range from 9.41±0.365 to 120.11±4.6 Bqkg^{-1} for ^{238}U, 5.12±0.3 to 109.59±6.6Bqkg^{-1} for ^{232}Th and 179.66±15.4 Bqkg^{-1} to 1183.05±102 Bqkg^{-1} for ^{40}K.

The maximum activity concentration of ^{238}U (120.113±4.6 Bqkg^{-1}) and ^{232}Th (109.59±6.6 Bqkg^{-1}) were observed in Amran and Al-Akil station beach (S-4) and (S-38), which is two of the famous historical and tourism places. The highest activity concentration of ^{40}K (1183.05±102Bqkg^{-1}) was found in Amran beach (S-4) nearer to little Aden city. The lowest concentration of all radionuclides was found at Roadsea Bridge beach (S-31) (TABLE 1), which may be due to high composition of Si.

TABLE 3 presents the absorbed dose rate, annual effective dose equivalent, external hazard index and representative level index values. The calculated absorbed gamma dose rate varied from 142.29 nGy h^{-1} (S-4, Amran beach) to 14.98 nGy h^{-1} (S- 31, Roadsea Bridge beach) with a mean of 78.01 nGy h^{-1} . The mean absorbed dose rate is found to be 1.53 times the world average value (51 nGy h^{-1}:[10]). The calculated values of annual effective dose rate ranging from 0.073 to 0.69 mSv, with a mean value of 0.38 mSv, which is lower than the world average value of 0.48mSv[10]. The calculated value of external hazard index ranges from 0.08

TABLE 1 : Geographical location and activity concentration of ^{238}U, ^{232}Th and ^{40}K in the beach sediment samples of Aden coast on gulf of Aden, south of Yemen.

S.no	Name of the site	Latitude	Longitude	Activity concentration (Bq/ kg)		
				^{238}U	^{232}Th	^{40}K
1	Kawa	12°44'.472	44°28'.367	69.74±2.68	77.56±4.7	1137.7±97.8
2	Mashhor	12°48'.395	44°33'.239	104.78±4.1	69.82±4.2	1076.4±92.6
3	Al-mansa	12°48'.302	44°40'.451	85.66±3.29	56.35±3.4	984.24±84.7
4	Amran	12°45'.273	44°43'.665	57.18±2.20	109.59±6.6	1183.1±102
5	Amran*	12°45'.277	44°44'.100	13.3375	14.32±0.87	291.45±25.1
6	Ras-Amran	12°44'.863	44°43'.162	18.33±0.71	36.89±2.25	542.64±46.7
7	Fakam	12°46'.351	44°47'.882	67.43±2.61	69.35±4.2	1063.1±91.4
8	Fakam*	12°44'.939	44°49'.648	15.1±0.58	47.51±2.9	444.17±38.2
9	Nasser houses	12°44'.163	44°52'.558	10.4±0.40	24.52±1.49	336.73±28.9
10	Al-adeer	12°44'.109	44°50'.055	34.1±1.31	31.63±1.93	451.38±38.8
11	Al-adeer Rest.	12°43'.988	44°53'.091	34.5±1.33	38.35±2.33	283.02±24.3
12	Koad-Anamer	12°44'.966	44°53'.468	20.7±0.81	29.1±1.77	236.69±20.4
13	Koad-Anamer*	12°45'.091	44°53'.957	14.98±0.58	17.13±1.04	390.54±33.6
14	Al-hisa	12°44'.789	44°54'.372	61.78±2.38	22.84±1.39	326.20±28.1
15	Br-Bra	12°44'.814	44°54'.839	22.57±0.87	49.11±2.99	354.67±30.5
16	Bridge	12°46'.459	44°53'.450	95.9±3.69	63.37±3.86	592.71±50.9
17	Al-farsi	12°47'.170	44°53'.698	37.26±1.10	35.39±2.15	616.56±53.1
18	Al-farsi*	12°46'.811	44°53'.679	22.66±0.68	35.99±2.19	794.46±68.3
19	Army comb	12°47'.901	44°53'.963	53.4±1.53	50.443±3.07	270.09±23.2
20	Gas station	12°48'.210	44°54'.154	47.097±1.8	48.6854±2.9	564.77±48.6
21	Iron factory	12°48'.474	44°54'.341	53.788±2.1	49.3226±3.0	478.89±41.2
22	Radio-station	12°48'.911	44°54'.744	60.66±2.3	42.291±2.58	689.23±59.3
23	Radio-station*	12°49'.105	44°54'.946	32.82±1.6	53.288±3.2	614.73±52.9
24	Power station	12°49'.458	44°55'.951	71.20±2.75	58.593±3.56	804.07±69.2
25	Ashaab city	12°49'.532	44°56'.243	47.66±1.8	65.27±3.98	751.15±69.6
26	Al-haswa Bridge	12°53'.955	44°58'.726	46.81±1.8	52.8038±3.2	688.55±59.2
27	Al-kasir Hotel	12°49'.642	44°57'.085	58.9±2.2	78.35±4.78	794.27±68.3
28	Anma City	12°49'.980	45°02'.914	69.94±2.6	43.96±2.60	739.21±63.6
29	haswa Mahmyia	12°49'.599	44°58'.058	54.44±2.1	60.86±3.70	664.10±57.1
30	haswa Mahmyia*	12°49'.469	44°58'.588	56.85±2.2	44.501±2.70	679.06±58.4
31	Roadsea Bridge	12°50'.564	45°00'.233	9.41±0.363	5.120±0.30	179.66±15.4
32	Labor Island	12°48'.656	45°01'.419	28.02±1.0	49.303±3.0	341.17±29.3
33	Al-arosa Rest.	12°46'.646	44°58'.764	26.16±1.0	9.598±0.58	226.09±19.4
34	Al-feel Gulf	12°46'.527	44°59'.076	29.17±1.1	36.124±2.21	474.04±40.8
35	Goldmor	12°49'.640	44°57'.084	51.87±2.0	28.3202±1.7	527.44±45.4
36	Golden club	12°46'.054	44°59'.374	50.5±1.9	30.39±1.8	781.46±67.2
37	Seara	12°46'.601	45°02'.758	93.32±3.59	50.37±3.1	721.89±62.1
38	Al-Akil station	12°47'.643	45°02'.383	120.11±4.6	49.27±3.01	931.32±80.1
39	Mercureo Hotel	12°48'.206	45°02'.478	51.57±1.98	102.91±6.28	1006.9±86.1
40	Aden University	12°48'.854	45°02'.619	26.92±1.03	20.21±1.23	922.65±79.4
41	Kornish Kahtan	12°49'.431	45°02'.747	21.80±0.8	82.56±5.03	796.48±68.5
42	Aden airport	12°49'.979	45°02'.914	25.93±1.0	41.17±2.5	775.36±66.7
43	Al-areish	12°50'.854	45°03'.216	41.90±1.6	80.056±4.88	1135.1±97.6
44	Al-alim	12°50'.759	45°04'.452	21.80±0.6	82.56±5.03	796.48±68.5
Aden Beach		Mean		46.32817	48.755	646.8159
		Minimum		9.41±0.36	5.12±0.30	179.66±15.4
		Maximum		120.11±4.6	109.59±6.6	1183.1±102

TABLE 2 : Comparison of activity concentrations of ^{238}U, ^{232}Th and ^{40}K in beach sediment samples of Aden coast on gulf of Aden, south of Yemen and other studies in different beaches of the world

Sl.no	Location	Mean activity concentration	(Bq/ kg)		Reference
		^{238}U	^{232}Th	^{40}K	
1	World	25	25	370	UNSCEAR2000
2	India	28.67	63.83	327.6	UNSCEAR2000
3	Beach sand Egypt	------	177	815	Uosif et al (2008)
4	Beach sand Read sea coast Egypt	23.1	7.2	338	Harb (2008)
5	Hungary	28.67	27.96	302.4	UNSCEAR2000
6	Kuwait	36	6	227	Al-Azmi (2002)
7	Nigeria	16	24	35	Arogunjo et al (2004)
8	Kalpakkam in Tamiln adu India	112	1455.8	351	Kannan et al (2002)
9	Ulla l in Karna taka , India	374	158	158	Radhakrishna et al (1993)
10	North east coast of Tamiln adu, India	7.82	24.52	274.87	Ramasamy et al (2009)
11	Aden coast on Gulf of Aden, south yemen	46.32817	48.755	646.8159	Present study

TABLE 3: The absorbed d ose rate, annual effective dose rate and hazard indices of all sites

Site number	Absorbed dose rate (nGy h^{-1})	Annual Effective dose rate(m Sv y^{-1})	Hazard indices	
			H_{ex}	Iγr
1	126.8561	0.622305	0.724514	1.9991
2	135.7909	0.666136	0.776562	2.11437
3	114.9546	0.563921	0.653743	1.790827
4	142.2989	0.698061	0.823632	2.265818
5	25.23639	0.1238	0.141306	0.400214
6	53.54431	0.262667	0.304809	0.852915
7	117.6911	0.577345	0.671031	1.85178
8	54.31315	0.266439	0.316507	0.871674
9	33.76149	0.16562	0.192811	0.539084
10	53.7837	0.263841	0.307934	0.844074
11	51.0126	0.250247	0.300292	0.802525
12	37.07291	0.181865	0.217455	0.58665
13	33.67471	0.165195	0.187848	0.531601
14	56.04537	0.274936	0.323019	0.857844
15	54.98382	0.269729	0.324336	0.877978
16	107.4817	0.527262	0.627124	1.668268
17	64.48495	0.316337	0.365525	1.013337
18	65.5799	0.321709	0.365405	1.040698
19	66.48999	0.326173	0.395282	1.040603
20	74.88584	0.36736	0.432683	1.177358
21	74.75433	0.366715	0.435369	1.171073
22	82.51668	0.404794	0.470524	1.286802
23	73.16886	0.358937	0.422259	1.161521
24	102.0573	0.500652	0.585837	1.596669
25	92.99306	0.456187	0.536999	1.47124
26	82.44107	0.404423	0.473552	1.299171
27	107.8615	0.529125	0.626636	1.705209
28	89.91965	0.44111	0.512493	1.398812
29	89.80941	0.440569	0.520222	1.414367
30	81.66686	0.400625	0.466662	1.276762
31	14.98583	0.073514	0.082553	0.233711
32	57.05694	0.279899	0.337039	0.907329
33	24.67547	0.121048	0.137483	0.376346
34	55.20959	0.270836	0.316892	0.871798
35	63.2227	0.310145	0.359194	0.980641
36	74.48744	0.365406	0.416169	1.161246
37	103.859	0.509491	0.59679	1.60713
38	124.3679	0.610099	0.70849	1.914352
39	128.2731	0.629256	0.746051	2.044165
40	63.40239	0.311027	0.342652	0.996783
41	93.39749	0.458171	0.543318	1.502039
42	69.41608	0.340528	0.390265	1.101548
43	115.3858	0.566037	0.658329	1.836624
44	23.07392	0.113191	0.133421	0.370737
Average	78.0179	0.382725	0.447928	1.227615
Minimum	14.98583	0.073514	0.082553	0.233711
Maximum	142.2989	0.698061	0.823632	2.265818

to 0.82. The representative level index value being 0.23 to 2.26, with the average of 1.22, higher than the world average (0.66 Bq kg^{-1}:[4]).

Large variation among the radioactivity concentration for different sites has been observed. It may be due to geological condition and drainage pattern of the study area. According to Harb, large variation of radionuclides in beach sediments may be due to the continuous wave action, as the waves reaches up to about 10m from the waterline during high tide and results in the fresh deposition of heavy minerals along the seashore. The high values could be explained as due to the presence of black sands, which are enriched in the mineral monazite containing a significant amount of ^{232}Th. The enrichment occurs because of the specific gravity of monazite allows its concentration along beaches where lighter materials are swept away[11]. The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K is 1.8, 1.9 and 1.7 times the world average values[10]. TABLE 2 shows the comparison of observed activity concentration of ^{238}U, ^{232}Th and ^{40}K in the present samples with literature values of different beaches.

CONCLUSION

The data obtained in the present work cover a wide area in the Aden coast on Gulf of Aden south of Yemen, which can be considered as the base-line of the region. The lowest concentration of uranium (9.41±0.36 Bq Kg-1) was observed in Roadsea Bridge beach sediment, and the highest (120.11±4.6 Bq Kg-1) in Al-Akil station sediment. Similarly, the lowest (5.12±0.30 Bq Kg-1) and highest (109.59±6.6 Bq Kg-1) levels of ^{232}Th were found in Roadsea Bridge sediment and Amran sediment. This indicates that the radioactive minerals are distributed erratically.The lowest (179.66±15.4 Bq Kg-1) and highest (1183.1±102 Bq Kg-1) levels of ^{40}K were found in Roadsea Bridge sediment and Amran sediment, respectively. Similarly, The total absorbed radionuclides from ambient air ranges from 14.98 nGy h-1 to 142.29 nGy h-1 with an average of 78.01nGy h-1. The highest dose rates were found in Amran, which were higher than the international recommended limit. Values of annual effective dose range from 0.073 mSv/year to 0.69 mSv/year with an average of 0.38 mSv/year which were higher than the international recommended limit. Values of I_{yr} range from 0.23 Bq/kg to 2.26 Bq/kg with an average of 1.22 Bq/kg which were higher than the international recommended limit. While the Hazard index values range from 0.082to 0.82 which were lower than the international recommended limit. Therefore the present study has pointed out the area under study need further studies in order to better understand the origin and distribution of naturally ocurring radionuclide.

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