Proceedings of Basic and Applied Sciences
ISSN 1857-8179 (paper). ISSN 1857-8187 (online). http://www.anglisticum.mk
Proceedings of the 1st International Conference on New Horizons in Basic and Applied Science, Hurghada – Egypt, Vol 1(1), 2013.

Natural Radioactivity of Ground Water in Some Areas in Aden Governorate South of Yemen Region

S. Harb*, A. H. El-Kamel, A. M. Zahran ** , A. Abbady*, and F.A. Ahmed*****
* Physics department, Faculty of Science, Qena 83523, South Valley University.Eygpt
**Physics department, Faculty of Science Assiut University, Eygpt
*** Physics department, Faculty of Science and Education-Sabir, Aden University.Yemen

Received November 13, 2013; Revised November 14, 2013; Accepted November 15, 2013

Abstract: *This paper presents the concentrations of naturally occurring radionuclides ^{226}Ra, ^{232Th} and ^{40}K measured in Groundwater collected from Aden Governorate South of Yemen Region using gamma spectroscopy. Thirty seven Groundwater samples were collected from four areas in Aden Governorate. The average activity concentrations for groundwater from Beer Ahmed area were 1.60 Bql^{-1}, 1.25 Bql^{-}and 16.90Bql^{-1} for ^{226}Ra, ^{232}Th and^{40}K respectively and from Beer Fadle area were 1.45Bql^{-1}, 0.87Bql^{-1} and 19.8Bql^{-1} for ^{226}Ra, ^{232}Th and ^{40} K, respectively, while that for groundwater samples from Daar-saad area were 1.27 Bql^{-1}, 1.18Bql^{-1} and 18.28 Bql^{-1} for ^{226}Ra, ^{232}Th and ^{40} K, respectively and Al-Masabian area were 1.55Bql^{-1}, 1.421Bql^{-1} and 19.03Bql^{-1} for ^{226}Ra, ^{232Th} and ^{40}K respectively. Also annual effective dose equivalent of ingestion of these waters was calculated. The results showed that the annual dose equivalent obtained in the present study was much higher than the recommended value (0.1mSv year^{-1}) as reported by WHO. The results were compared with those for drinking water.*

Key words: *Radioactivity, South Yemen, Aden Governorate, Groundwater, annual Effective dose*

Introduction

Determination of naturally occurring radionuclides in groundwater is useful as a direct input to environmental and public health studies [14]. Considering the high radiotoxicity of ^{226}Ra and ^{228}Ra, their presence in water and the associated health risks require particular attention. The presence of ^{226}Ra in water depends on the water's origin. For well or mineral water, it depends on the content of ^{238}U in the solids of the aquifer where the water is stored. The geochemical characteristics of the aquifer determine the dissolution of radium from the solids into the water. ^{226}Ra is known to be removed by the treatment of water in purification plants [8].

Radium has two natural isotopes which are of concern in public water supplies: ^{226}Ra, an alpha emitter with a half-life of 1622 years generated through the decay of ^{238}U, and ^{228}Ra a shorter-lived beta-emitter (half-life 5.7 years), which is generated directly by ^{232}Th decay. The distributions of ^{226}Ra and ^{228}Ra in water are a function of the Th and U contents in the aquifer, the geochemical properties of the aquifer solids, and the half-lives of each isotope (ICRP, 1993).

The groundwater in Aden Governorate used for drinking . The main sources in the Aden Governorate south Yemen are wells. Since the base line concentration of natural radioactivity in groundwater in Aden Governorate south Yemen is not known, the levels of ^{226}Ra, ^{232}Th and ^{40} K were investigated in representative drinking water to assess the radiological risk resulting from the consumption of this water.

ISSN 1857-8179 (paper). ISSN 1857-8187 (online). http://www.anglisticum.mk
Proceedings of the 1st International Conference on New Horizons in Basic and Applied Science, Hurghada – Egypt, Vol 1(1), 2013.

Materials and methods
Description of study areas

The Republic of Yemen is located in the southern sector of theArabian Peninsula (Fig. 1). The study Aden Governorate area(~750km^2) is located some (400 km) south of Sana'a.and located in Lat. 12°54'.211N and long 12°53'.294E Aden Governorate area consists of tertiary volcano that is comprised of basalt flows, ignimbrites and tuffaceous rocks [10].

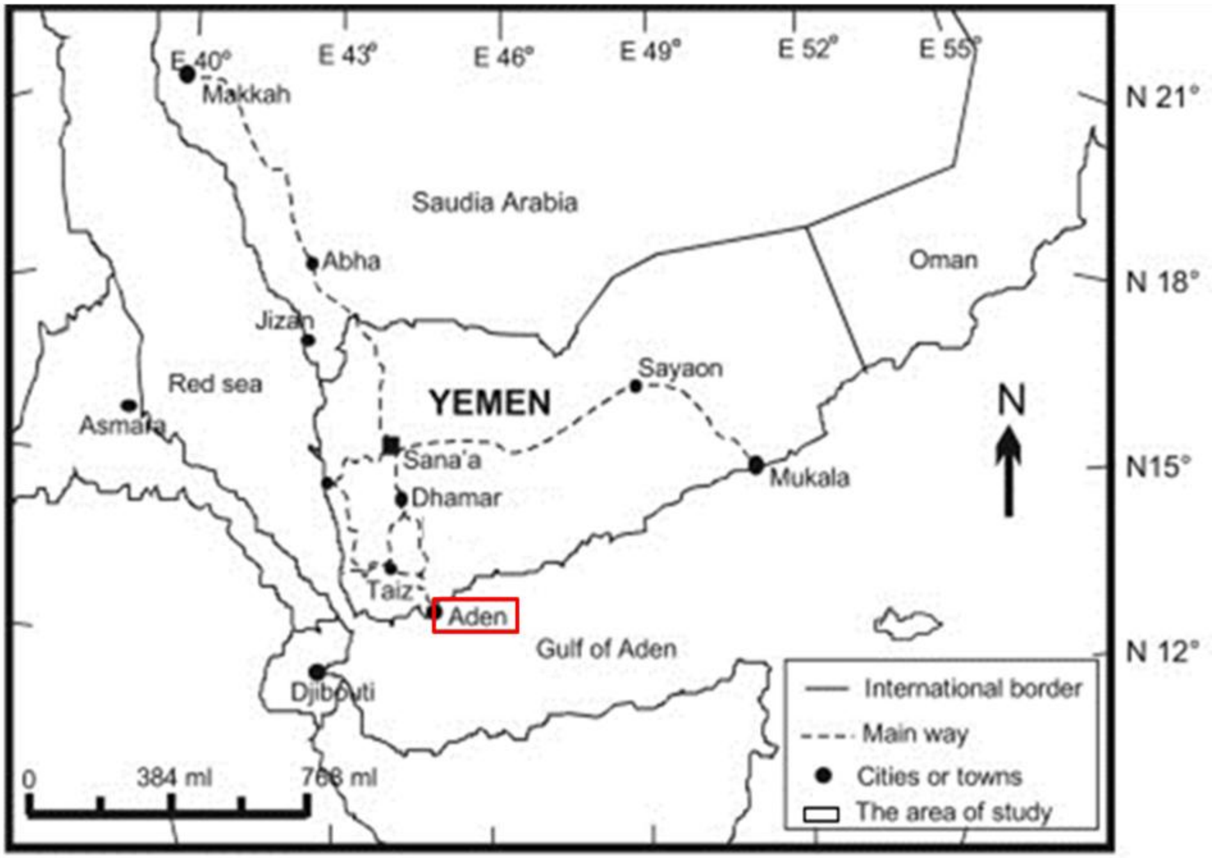

Fig.1. illustrates the areas under study.

Sample collection and preparation techniques

Because no running water in this area 37 groundwater samples were collected from the study area that used as drinking water. Measuring pH values as well as conductivity for water samples were measured in the laboratory. Standard polyethylene Marinelli beakers (1 liter) were used as a Sampling and measuring container. Before use, the containers were washed with dilute hydrochloric acid and rinsed with distilled water. Each beaker was filled up to brim and a tight cap was pressed on so that the air was completely removed from it.

The collected water samples were left for an overnight period in polyethylene containers to allow setting of any suspended solid materials and for each samples a clear supernatant was separated decantation. The clear solution was acidified by adding 0.5ml of conc. HNO_3 per liter, to prevent any loss of radium isotopes around the container walls, and to avoid growth of microorganisms [26].The water samples were then homogenized well by shaking. The final acidity of water samples reaches pH-2. The samples were stored for over 30 days to reach secular equilibrium before radiometric analysis.

Gamma-Ray Detection System

Each sample was measured with a gamma-ray spectrometer consisting of a NaI (Tl) setup and multi channel analyzer 8192 channel, with the following specifications: resolution (FWHM) at 1.33 MeV ^{60}Co is 60 keV- relative efficiency at 1.33 MeV ^{60}Co is 7.5 %. The detector is shielded in a chamber of two layers starting with stainless steel (10 mm thick) and leads (30 mm thick). This shield serves to reduce different background radioactivity. The system was calibrated for energy and efficiency. The spectrometer was calibrated for efficiency and energy using multinuclide standard solution (QCYB41) DKD (Germany). The standard source peaked in the same geometry as that used for measured samples. For calibration, the standard source is placed above the detector, and the measurement started. The dependence of the efficiency on the radiation energy was determined at 0.0 mm sample detector distance. The absolute efficiency of the NaI(Tl) detector was determined using the standard solution QCYB41DKD (Germany).The detector efficiency decreases continuously with energy. The dependence of the efficiency on the volume of the sample was determined by a Marinelli beaker (1 liter). It can be noticed that the detector efficiency decreases with the volume of the sample in the energy range of interest. Finally, each sample was placed in a Marinelli beaker of the same size as that of the multi-element standard. Then each sample spectrum was acquired for 24 h. The spectra were either evaluated with the computer software program software Gene 2000, or manually with the use of a spread sheet (Microsoft Excel) to calculate the natural radioactivity. Also, the measurement uncertainty is reported.^{226}Ra activity of the samples was determined via its daughters (^{214}Pb and ^{214}Bi) through the intensity of the 295.22, 351.93 keV, for ^{214}Pb Gamma-lines and 609.31, 1120, 1764.49 keV, for ^{214}Bi Gamma-lines.^{232}Th activity of the sample was determined from the daughters (^{228}Ac), (^{212}Pb) and (^{208}Tl) through the intensity of 209.25, 338.32,911.2 keV Gamma-lines for (^{228}Ac), (^{212}Pb) emissions at 238.63 keV and (^{208}Tl) emissions at 583.19, 2614 keV Gamma-lines.^{40} K activity determined from the 1460.7 keV emissions Gamma-lines.

Dose calculation

In order to evaluate potential health hazards, doses due to ingestion of these waters were estimated to assess the contribution of these radionuclides to public exposure from natural radioactivity. The following equation was used to calculate the doses [6, 17].

$$DR_w = A_w x\ IR_w x ID_F \qquad (1)$$

where DR_w the effective dose (mSv year^{-1}), A_w activity (Bql^{-1}),IR_w intake of water for person in 1 year and ID_F the effective dose equivalent conversion factor (mSv Bq^{-1}).

Doses were estimated by considering a consumption rate (150, 350 and 500 l year^{-1}) for infants, children and adults, respectively, and the conversion factors (2.8×10^{-7}, 2.3×10^{-7} and 5×10^{-9} Sv Bq^{-1}) for ^{226}Ra, ^{232}Th and^{40} K, respectively, for adults reported by ICRP, IAEA and WHO [11, 13, 27].

Results and Discussion

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40} K in the groundwater that is used as drinking water in Beer Ahmed, Beer Fadle, Daar-Saad and Al-Masabian areas in Aden Governorate South of Yemen Region together with location, pH and conductivity are presented in Table 1. As seen, water samples from Beer Ahmed area have pH ranging from7.79-8.31, while that from Beer Fadle area have pH ranging from 8.25-8.53. For Daar-Saad and Al-Masabian area have pH ranging from 8.13-8.55and 8.24-8.45. The concentrations of ^{226}Ra,^{232}Th and^{40} K varied from 0.33-2.67Bql^{-1}, 0.15-2.72Bql^{-1}and 7.87-19.48Bql^{-1}and from 0.46-2.44Bql^{-1},0.53-1.22Bql^{-1} and18.29-21.32Bql^{-1}respectively,at Beer Ahmed and Beer Fadle area, For Daar-Saad and Al-Masabian area the concentrations of ^{226}Ra, ^{232}Th and ^{40} K ranged from 0.22-2.45Bql^{-1}, 0.18-2.31Bql^{-1}and13.07-26.02Bql^{-1}andfrom1.07-2.29Bql^{-1},0.57-3.06Bql^{-1}and15.55 23.97Bql^{-1}respectively. The values of ^{226}Ra in groundwater samples from Beer Ahmed, Beer Fadle, Daar-Saad and Al-Masabian areas in Aden Governorate are much higher than the maximum contaminant levels of 1.85 mBql^{-1} proposed in the USA (US [6]) for drinking water in the other hand the concentrations of radionuclide's ^{226}Ra, ^{232}Th and ^{40} K in water samples from Beer Ahmed, Beer Fadle, Daar-Saad and Al-Masabian areas in Aden Governorate were found in the narrow range, this probably is due to the fact that the sites studied cover an area with similar aquifer lithologies and consequently no large differences in radionuclide solubilities and mobilities [7].The abundance of ^{40} K activity observed in the water samples from Beer Ahmed, Beer Fadle, Daar-Saad and Al-Masabian areas in Aden Governorate area may be due to agricultural activities going on in the area that involve the use of potassium fertilizers which may have been transported to the groundwater, given that ^{40} K is a highly soluble element it should be noted that in all the sites studied, concentrations of ^{226}Ra is higher than that of ^{232}Th and this reflects the fact that radium is more soluble in groundwater than its thorium and uranium precursors, and its solubility is enhanced by: 1) the common-ion effect (when dissolved solids are high), 2) an oxygen-poor environment, and 3) the fragmentation of uranium-bearing minerals [15].

Table 1: Associated characteristics and activity concentration (Bql^{-1}) of natural radionuclides in groundwater at various sampling sites in Aden Governorate South of Yemen Region.

Sample No.	Area	Latitude	Longitude	pH	Conduct.	Activity concentration (Bq/ L)		
						226Ra	232Th	40K
1	Beer Ahmed	12°50’.323	44°57’.162	8.28	4.06	2.51	2.72	17.87
2		12°53’.295	44°54’.541	8.31	5.07	2.67	2.52	19.15
3		12°53’.037	44°55’.369	8.11	3.38	1.66	0.27	16.60
4		12°53’.397	44°55’.021	8.31	4.55	1.83	0.95	19.75
5		12°54’.103	44°54’.564	8.23	2.76	1.76	1.26	19.48
6		12°54’.334	44°55’.686	7.79	4.2	1.73	2.01	16.97
7		12°53’.974	44°53’.938	8.23	3.99	0.33	0.15	7.87
8		12°53’.361	44°54’.321	8.18	5.39	0.34	0.18	17.51

				Mean Value		1.603	1.257	16.9
9	Beer Fadle	12°54'.620	44°57'.311	8.25	8.53	0.46	1.22	18.29
10		12°50'.925	44°57'.407	8.53	1.79	2.44	0.53	21.32
				Mean Value		1.45	0.875	19.8
11	Daar-saad	12°54'.975	44°55'.993	8.43	2.75	1.74	0.61	20.01
12		12°54'.974	44°55'.994	8.43	2.30	2.45	2.31	18.59
13		12°55'.138	44°55'.749	8.34	3.14	1.92	1.92	16.21
14		12°55'.753	44°55'.630	8.31	3.37	0.27	0.32	13.07
15		12°55'.693	44°55'.633	8.37	3.22	1.74	0.96	18.85
16		12°55'.434	44°55'.561	8.39	2.58	2.36	2.22	13.78
17		12°55'.801	44°54'.931	8.55	2.19	0.26	0.18	14.50
18		12°55'.815	44°54'.937	8.48	1.89	1.15	1.89	16.05
19		12°56'.093	44°55'.643	8.47	2.02	0.22	0.39	16.22
20		12°55'.932	44°55'.666	8.40	1.88	0.36	0.96	26.02
21		12°55'.927	44°55'.670	8.43	2.99	2.16	1.64	20.87
22		12°54'.191	44°57'.205	8.21	4.27	0.62	1.67	25.07
23		12°53'.953	44°58'.123	8.36	2.60	1.36	0.67	19.99
24		12°53'.961	44°57'.564	8.20	5.01	1.93	1.14	18.14
25		12°53'.966	44°57'.570	8.23	4.5	1.12	1.16	15.05
26		12°54'.331	44°57'.443	8.14	2.80	1.12	1.65	18.46
27		12°54'.623	44°57'.316	8.13	3.18	0.84	0.50	19.98
				Mean Value		1.27	1.18	18.28
28	Al-Masabian	12°44'.711	44°51'.707	8.35	2.26	1.56	1.15	19.29
29		12°54'.158	45°00'.653	8.27	4.62	1.11	1.92	15.75
30		12°54'.158	45°00'.653	8.27	3.14	1.53	1.31	19.44
31		12°54'.833	45°00'.453	8.31	2.53	1.59	1.67	23.97
32		12°53'.684	44°59'.735	8.24	7.18	2.29	1.20	17.92
33		12°53'.819	44°59'.761	8.27	5.3	1.54	0.57	20.94
34		12°53'.795	44°59'.707	8.34	4.1	1.94	0.81	19.04
35		12°54'.754	45°00'.043	8.28	2.18	1.79	3.06	18.08
36		12°54'.779	44°59'.435	8.45	3.85	1.15	0.64	20.34
37		12°53'.953	44°58'.124	8.36	4.17	1.07	1.88	15.55
				Mean Value		1.557	1.421	19.03

Comparison of results with similar in other countries

Table 2 summarizes the values of ^{226}Ra, ^{232}Th and ^{40}K concentrations in other countries and those from the present work. As can be seen from Table 2, ^{226}Ra values from the present work are higher than that reported by [3] for ground water at Egypt (Qena) and Egypt (Safaga),[4] Sudan for ground water,[19] Syria for spring water,[28]China for ground water and [23] Italy for drinking water and lower than the values reported by [, ,2, 9, 14,15, 16, 21,22,24].Also ^{232}Th activity concentrations obtained in this study are matches than that reported by [21] for hot spring water at Afra, Barbeita and Al-Amir sites in Jordan and is higher than that reported by [3] for groundwater in Egypt and [4] for groundwater in Sudan and lower than that reported by [2] for lake water in Nigeria. On the other hand, ^{40}K values in the present study match with those values reported by [1] for spring water Yemen (Dempt) and lower than value reported by [2] for lake water in Nigeria.

Table 2: The activity concentration in Bql^{-1} of water samples in the present investigation in comparison with other countries.

Country	Type of water	Activity concentration (Bql−1)			Ref.
		226Ra	232Th	40K	
South Yemen	(Ground W.) Beer Ahmed (Ground W.) Beer Fadle (Ground W.) DaarSaad (Ground W.) Al-Masabian	0.33-2.67 0.46-2.44 0.22-2.45 1.07-2.29	0.15-2.72 0.53-1.22 0.18-2.31 0.57-3.06	7.87-19.48 8.29-21.32 13.07-26.02 15.55-23.97	Present work
South Yemen	Groundwater (Ass - Alh)	2.01–6.55	1.07–2.93	ND	[1]
Yemen	Groundwater (Juban)	2.25–3.45	0.3–1.43	26.73–43.7	[1]
Yemen	spring water(Dempt)	1.19–5.48	ND–2.17	5.64–22.5	[1]
Egypt (Qena)	Groundwater	Mean 0.08	Mean 0.04		[3]
Egypt (Safaga)	Groundwater	Mean 0.1	Mean 0.05		[3]
Jordan	Hot spring	3.8–6.8	1.42–2.37		[21]
Tunisia	springs	0.034–3.9			[16]
Sudan	Groundwater	0.007–0.014	0.001-0.039		[4]
Syria	Well water	Mean 0.042			[19]
Nigeria	lakes water	Mean 12	Mean 12	Mean 97	[2]
brazil	Groundwater	0.01–3.79			[9]
U.S.A	Mineral water(Saratoga)	Max 20			[15]
China	Groundwater	Max 0.93			[28]
Sweden	Groundwater	0.016–4.9			[14]
Finland	Groundwater	0.01–49			[22]
Italy	Drinking water	0.002–1.2			[23].
Spain	Natural water	0.02–4			[24]

Radiation dose estimation

Table 3 shows the calculated effective dose for different age groups infants, children and adults, considering only the ingestion from ^{226}Ra and ^{232}Th. The reason for not considering ^{40}K in these calculations is due to the absorption of the essential element potassium is under homeostatic control and takes place mainly from ingested food. Thus, the contribution to dose from the ingestion of ^{40}K in water, with its relatively low dose conversion factor (5×10^{-9}Sv Bq^{-1}), will be much less than that of many other radionuclides. It should be noted that doses were ranged from 2.82-6.02mSv year^{-1} with average value of 3.22mSv year^{-1} for water from Beer Ahmed area, from 2.34-3.67mSv year^{-1} with average value of 3.00mSv year^{-1} for water from Beer Fadle area, from 0.692-6.65mSv year^{-1} with average value of3.62mSv year^{-1}for water from Daar-Saad and from 0.59-5.87mSv year^{-1} area with average value of 2.52 for adults. From Table 3, it can be observed that, doses received by adults are higher than that received by infants and children and the main dose contribution of these waters is caused by ^{226}Ra in the bones. According to the recommended reference level of 0.26, 0.2 and 0.1 mSv year^{-1} for effective dose for infants, children and adults, respectively, published by WHO, IAEA and UNSCEAR [12,25,26], from one year consumption of drinking water, the doses obtained in our study are much higher than the recommended reference level and consequently, it can be recommended that, the investigated waters are not acceptable for life-long human consumption and a reduction in consumption or radionuclide concentration is necessary.

Table: 3 Estimates of annual effective doses mSv year^{-1} due to ingestion of ^{226}Ra and ^{232}Th for different age groups.

Sample No.	Ra-226 mSv y^{-1}			Th-232mSv y^{-1}			Total ingestion mSv y^{-1}		
	infants	children	Adults	infants	children	Adults	infants	children	Adults
1	0.65	1.53	2.19	0.39	0.93	1.33	1.04	2.46	3.52
2	0.46	1.09	1.55	0.66	1.54	2.21	1.12	2.63	3.76
3	0.64	1.51	2.15	0.45	1.06	1.51	1.09	2.57	3.66
4	0.67	1.56	2.23	0.57	1.34	1.92	1.24	2.9	4.15
5	0.96	2.25	3.21	0.41	0.97	1.38	1.37	3.22	4.59
6	0.64	1.51	2.16	0.19	0.46	0.66	0.83	1.97	2.82
7	0.81	1.90	2.72	0.28	0.65	0.94	1.09	2.55	3.66
8	0.75	1.75	2.50	1.05	0.002	3.52	1.8	1.752	6.02
Mean	0.558	1.31	1.871	0.4	0.6952	1.347	0.958	2.0052	3.218
9	0.48	1.12	1.61	0.22	0.51	0.73	0.7	1.63	2.34
10	0.45	1.05	1.50	0.65	1.51	2.17	1.1	2.56	3.67
Mean	0.465	1.085	1.555	0.435	1.01	1.45	0.9	2.095	3.005
11	0.57	1.34	1.91	0.23	0.54	0.77	0.8	1.88	2.68
12	0.81	1.89	2.70	0.39	0.92	1.31	1.2	2.81	4.01
13	0.47	1.10	1.57	0.40	0.93	1.33	0.87	2.03	2.9
14	0.47	1.09	1.56	0.57	1.33	1.90	1.04	2.42	3.46
15	0.35	0.82	1.17	0.17	0.40	0.57	0.52	1.22	1.74
16	0.19	0.45	0.64	0.41	0.97	1.39	0.6	1.42	2.03
17	0.10	2.39	3.42	0.18	0.42	0.61	0.28	2.81	4.03
18	0.10	2.46	3.52	0.93	2.19	3.13	1.03	4.65	6.65
19	0.11	2.61	3.73	0.87	2.03	2.90	0.98	4.64	6.63
20	0.70	1.63	2.33	0.009	0.22	0.31	0.709	1.85	2.64
21	0.77	1.79	2.56	0.32	0.76	1.09	1.09	2.55	3.65
22	0.74	1.72	2.46	0.43	1.02	1.45	1.17	2.74	3.91
23	0.72	1.69	2.42	0.69	0.001	2.31	1.41	1.691	4.73
24	0.73	1.70	0.002	0.20	0.48	0.69	0.93	2.18	0.692
25	1.03	2.40	3.43	0.79	1.86	2.66	1.82	4.26	6.09
26	0.80	1.88	2.68	0.66	1.55	2.21	1.46	3.43	4.89
27	0.11	0.266	0.37	0.11	0.26	0.37	0.22	2.48	0.74

Mean	0.5158	1.6015	2.145	0.4328	0.93417	1.470	0.9487	2.6506	3.616
28	0.73	1.70	2.44	0.33	0.77	1.11	1.06	2.47	3.55
29	0.99	2.31	3.31	0.76	1.79	2.56	1.75	4.1	5.87
30	0.11	0.259	0.37	0.006	0.15	0.22	0.116	0.412	0.59
31	0.48	1.13	1.61	0.65	1.52	2.17	1.13	2.65	3.78
32	0.009	0.216	0.31	0.13	0.32	0.45	0.139	0.535	0.76
33	0.15	0.358	0.51	0.33	0.77	1.11	0.48	1.13	1.62
34	0.91	2.12	3.03	0.56	1.32	1.88	1.47	3.44	4.91
35	0.26	0.615	0.87	0.57	1.34	1.92	0.83	1.96	2.79
36	0.14	0.327	0.46	0.005	0.12	0.17	0.145	0.45	0.63
37	0.14	1.53	0.47	0.006	0.15	0.21	0.146	1.68	0.68
Mean	0.3919	1.0565	1.338	0.3347	0.825	1.18	0.7266	1.8827	2.518

Conclusion

The natural radioactivity levels of ^{226}Ra, ^{232}Thand ^{40} K have been measured in water samples in Beer Ahmed, Beer Fadle, Daar-Saad and Al-Masabian areas in Aden Governorate using gamma ray spectroscopy. The activity profiles of the radionuclides have clearly showed high activity concentrations across the study areas. The high activity concentrations for ^{226}Ra and ^{232}Th measured in water samples explain the relationship between the groundwater and bedrocks in these areas, for this reason we suggest that the investigated groundwater are not acceptable as a drinking water.

References

1. Abdallah Ibrahim Abd El-Mageed , Abd El-Hadi El-Kamel , Abd El-Bast Abbady,,Shaban Harb , Imran Issa Saleh,1. Natural radioactivity of ground and hot spring water in some areas,Desalination, 15 July (2013) 28-31.
2. E.O. Agbalagba, R.A. Onoja, Evaluation of natural radioactivity in soil, sediment and water samples of Niger Delta (Biseni) Flood Plain Lakes, Nigeria, J. Environ. Radioact. 102 (2011) 667–671
3. N.K. Ahmed, Natural radioactivity of ground and drinking water in some areas of Upper Egypt, Turk. J. Eng. Environ. Sci. 28 (2004) 345–354.
4. A.A. Alfatih, S. Isam, A. Ibrahim, Saif El Din, M.B. Siddeeg, Eltayeb Hatem, Idriss Hajo, HmzaWalid, E.H. Yousif, Investigation of natural radioactivity levels in water around Kadugli, Sudan, Appl. Radiat. Isot. 66 (2008) 1650–1653.
5. S. Al-Khirbash, M.A. Takla, M. Abdulwahad, Sh. Sakran, Trectonic evaluation of the Southeast Precambrian Complex, Yemen Sana'a Univ, Sci. Bull. 14 (2001) 67–83.
6. EPA, Final draft for the drinking water criteria document on radium, US Environmental Protection Agency, Washington, Dc, 1999 Tr-1241-85.
7. A.I. El-Mageed, A.H. El-Kamel, A. Abbady, S. Harb, A.M.M. Youssef, I.I. Saleh, Assessment of natural and anthropogenic radioactivity levels in rocks and soil in the environments of Juban Town in Yemen, Radiat. Phys. Chem. 80 (2010) 710–715.

8. M. Gascoyne, High levels of uranium and radium in groundwater at Canada's Underground, Appl. Geochem. 4 (1989) 557–591.
9. J.M. Godoy, M.L. Godoy, Natural radioactivity in Brazilian groundwater, J. Environ. Radioact. 85 (2006) 71–83.
10. Heikal, M.T.S. (1987). Geology of the Precambrian Rocks at Hajjah district, Yemen, Ph. D. Thesis, Tanta Univ., p 532.
11. IAEA, International basic safty standards for protection against ionizing radiation and for the safety of radiation sources. Safety series 15, Vienna,1996.
12. IAEA, Specification of Radionuclide Content in Commodities Requiring Regulation For Purposes of Radiation Protection Safety. Guide (Draft), Vienna, 2002.
13. ICRP, 72, Age-dependent doses to members of the public from intake of radionuclides: Part 5, Compilation of Ingestion and Inhalation Dose Coefficients, Annals of The ICRP, 26 (1), ICRP Publication 72, Pergamon Press, Oxford, 1996.
14. M.M. Isam Saleh, H.B.L. Pettersson, E. Lund, Uranium and thorium series radionuclides In drinking water from drilled bedrock wells: correlation to geology and bedrock Radioactivity and dose estimation, Radiat. Prot. Dosim. 102 (3) (2002) 249–285.
15. M.E. Kitto, M. Sook Kim, Naturally occurring radionuclides in community water Supplies of New York State Heal. Phys. 88 (2005) 253–260.
16. S. Labidi, M. Dochraoui, H. Mahjoubi, N. Lemaitre, R. Ben Salah, S. Mtimet, Natural Radioactive nuclides in some Tunisian thermo-mineral springs, J. Environ. Radioact. 62 (2002) 87–96.
17. D. Meltem, K. Gursel, Natural radioactivity in various surface waters in Adana, Turkey, Desalination 261 (2010) 126–130.
18. J.D. Navratil, R.D. Greenwell, F. Macasek, Radioactive waste management and Environment restoration, Proc. Int. Conf. Singapore; Oct. 12–16, 1997, 1997.
19. I. Othman, T. Yassine, Natural radioactivity of drinking water in the southern and middle parts of Syria, Environ. Int. 22 (1996) 355–359.
20. Sakran, Sh. 1993: The Geology of the Basement Rocks of Al-Sawadia Area, Al-bayda District, Yemen, Ph. D. Thesis, Cairo Univ. 248p.
21. S.A. Saqan, M.K. Kullab, A.M. Ismail, Radionuclides in hot mineral spring waters in Jordan, J. Environ. Radioact. 52 (2001) 99–107.
22. L. Salonen, 238U series radionuclides as a source of increased radioactivity in Groundwater originating from finish bedrock. 71–84, in: J. Soukko (Ed.), Future Groundwater Resources at Risk, IAHS Publication No. 222. IAHS Press, Oxfordshire, 1994.
23. G. Sgorbati, M. Forte, Determination of ^{238}U and ^{226}Ra concentrations in drinking Waters in Lombaradia Region, Italy, Communication to UNSCEAR Secretariat, 1997.
24. J. Soto, L.S. Quindos, N. Diaz- Caneja, ^{226}Ra and ^{222}Rn in natural waters in tow typical Locations in Spain, Radiat. Prot. Dosim. J. 24 (1988) 93–95.
25. UNSCEAR, 2000, Report to General Assembly. Annex B: Exposure from Natural Radiation Sources. And, Report to General Assembly. With Scientific Annexes. Sources and Effects of Ionizing Radiation. United Nations Sales Publications No. E.00.IX.3 Volume I: Sources and No. E.00.IX.4 (Volume II: Effects). United Nations, New York, 1220 pp.
26. WHO, World Health Organization, 2nd Ed., Guidelines for Drinking Water Quality, Vol. 2, 1996, Geneva, Switzerland.
27. WHO, World Health Organization, Guidelines for Drinking Water Quality, Vol. 3- Chapter 9 Drafts, 2003, Geneva, Switzerland.
28. W. Zhuo, T. Lida, X. Yang, Occurrence of ^{222}Rn, ^{226}Ra, ^{228}Ra and U in groundwater In Fujian Province, China, J. Environ. Radioact. 53 (2001) 111–120.