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RESEARCH ARTICLE

MEASUREMENT OF NATURAL RADIOACTIVITY IN TAP WATER SAMPLES FOR SELECTED REGIONS IN ADEN GOVERNORATE, YEMEN

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Abstract

In the present work, we have measured specific activity concentrations of in eleven tap water samples for selected regions in Aden governorate by using high purity germanium detector (HPGe). The (HPGe) detector (CANBERA-model 7229N, USA) with an efficiency of 35% and energy resolution (2.6keV) at energy (1332.6keV) for ^{60}Co, the high purity N-type semiconductor detector with physical characteristics of (geometry closed-end coaxial, (3×3 inch). The results have shown that, The highest value of specific activity concentration of ^{226}Ra was found in in T7 Daar-Saad region which was equal to (0.525±0.29)Bq/L, while the lowest value of specific activity concentration of ^{226}Ra was found in T11 Aden Assughra region which was equal to (0.017±0.006)Bq/L with an average value of (0.228±0.13)Bq/L. The highest value of specific activity concentration of ^{232}Th was found in in T5 Khor-makser region which was equal to (0.319±0.18)Bq/L, while the lowest value of specific activity concentration of ^{232}Th was found in T11 Aden Assughra region which was equal to (0.009±0.001)Bq/L with an average values of (0.129±0.089)Bq/L. The highest value of specific activity concentration of (^{40}K) was found in in T2 (Al-Ma·allah) region which was equal to (0.4±0.26)Bq/L, while the lowest value of specific activity concentration of (^{40}K) was found in T11 Aden Assughra region which was equal to (0.027±0.004)Bq/L with an average values of (0.141±0.021)Bq/L respectively. The annual ingestion effective dose (AED) ranged from (3.05 to 98.77µSv/y), (5.67 to 178.16µSv/y), and (3.41 to 119.08µSv/y), with average values of 42.65µSv/y, 78.62µSv/y and 48.62µSv/y, for infants, children and adults respectively. The excess lifetime cancer risk (ELCR) have been calculated, its values were lower than the world's average value of (0.29×10^{-3}) as reported by EPA. The overall annual effective dose and cancer risks corresponding to radionuclide intake in tap water were below the recommended maximum values. It was inferred from the findings of this study that the water used as the sample does not have any significant radiological impacts to human body and is safe to be used as drinking water.

Keywords: Tap water, Specific Activity, Annual Absorbed Dose, Aden Governorate, Cancer Risk.

1. Introduction

Water is one of the main important elements for life and environment balance, and it's the main reason behind development countries in the world. Water must be free from pollution because it is necessary and precious natural resource for the creature's life. The measurement of natural radioactivity in our physical environment indicates how much pollution caused by radiation exposure [1, 2]. Natural radioactivity in water has been examined widely in different parts of the world to assess the radiological risks to people in view of using tainted water. Radioactive materials enter explicitly into the body through drinking or as part of advanced lifestyles. They cause health problems as a result of the decay of these radionuclides into the body [3, 4]. Due to the importance of drinking water for human life, their quality must be carefully and systematically controlled. The recommended control of radioactivity levels in drinking water can be achieved by the determination of the activity levels in all types of drinking water, in order to guarantee an exposure lower than 0.1mSv/y, recommended by the WHO (World Health Organization) [5]. Drinking water can have three radioactive chains, Uranium, Thorium, Actinium, including the natural Radium, Uranium elements, as well as Radon gas. These elements have diverse biological affect that damage human body, e.g. Radium converges in the bones that can be the reason of cancer. Uranium has a poisonous effect on the kidneys and causes bones cancer. There are two sources of ionizing radiation: natural radioactive material and manufactured sources. The natural radioactive material that can occur in nature is categorized into two types: Cosmic Rays and Terrestrial Origin- Ray [6,7]. Exposure to radionuclides from drinking water results in the increased risk of cancer. The radioactive particles (alpha, beta) and gamma photons emitted by radionuclides are called ''ionizing radiation'' because they ionize (''destabilize'') nearby atoms as they travel through a cell or other material. In living tissue, this ionization process can damage chromosomes or other parts of the cell. This cellular damage can lead to the death of the cell or to unnatural reproduction of the cell. Exposure to elevated uranium levels in drinking water has been shown to lead to changes in kidney function that are indicators of potential future kidney failure [8,9]. From the biological effect of radiation protection opinion, the UNSC established that the world average dose from natural radiation sources of the natural area is (2.4mSv/y) and about (0.8mSv/y) by man-made [10]. The aim of this study is to assess the radioactive contamination such as Radiun-226, Thorium-232, and Potasuim-40 in tap water samples for some selected regions in Aden governorate by using (HPGe) detector. Also, in this study we calculated the radiological parameters due to natural radioactivity in all samples consumes daily by people which make them in danger of this pollution.

2. Materials and Methods

2.1. Description of Study Area:

In Aden governorate, the household water is supplied from two sources; one from Beer Nasser region in Lahj governorate and other from Beer Ahmed region in the north side of the Aden governorate. In fact, the study area is located inside Aden Governorate which is located in South of Yemen on the Gulf of den. The location of Aden Governorate has been determined using the Global Positioning System (GPS): Latitude: 12°49'.468"N., Longitude: 44°51'.708"E. The map of studied area is shown in Figure (1). Table (1) shows symbol and location name for the different studied regions (sites) in Aden governorate for tap water samples.

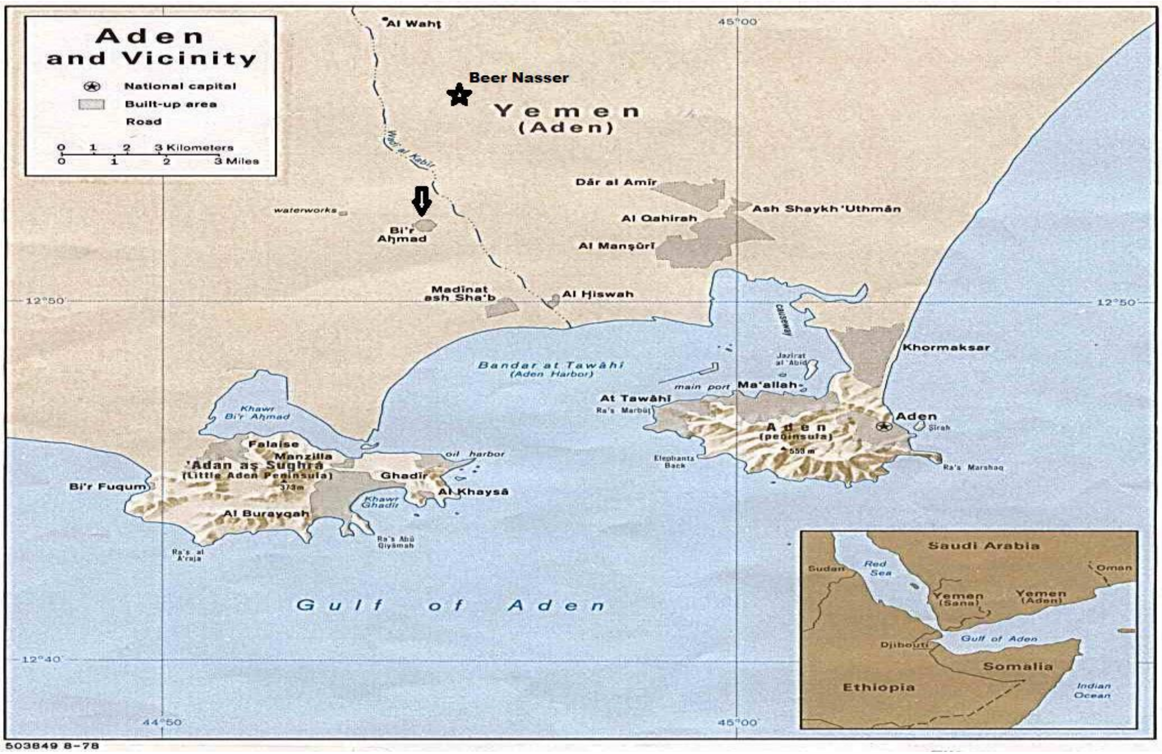

Fig. 1: Illustrates the areas under study

2.2. Collection and Preparation of the samples:

Tap water samples were obtained from the water networks in dwellings from different locations in Aden Governorate, Yemen. For 226Ra, 232Th, 40K activity concentrations measurements by using gamma spectroscopy, Measuring pH values as well as conductivity for water samples were measured. Standard polyethylene Marinelli beakers (1.0liter) 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. HNO3 per liter, to prevent any loss of radium isotopes around the container walls, and to avoid growth of microorganisms [11].The water samples were then homogenized well by shaking. The final acidity of water samples reaches pH=2. The samples were stored for over 30days to reach secular equilibrium between radium isotopes and their respective daughters before radiometric analysis.

2.3. Radioactivity analysis:

All the samples were measured at the nuclear physics laboratory in atomic energy organization laboratory, Sana'a, Yemen using a gamma ray spectrometer. The applied low level background gamma ray spectrometer consists basically of an HPGe-detector the detector was coaxial in shape having relative efficiency 35% with respect to NaI (TI) detector and active volume of 180cm3 fitted with beryllium-end window. The detector had closed-end coaxial Gamma-ray detectors (p-type) made up of high purity germanium (HPGe) in a vertical configuration cooled by liquid nitrogen with the following specifications: resolution (FWHM) ≤ 2.000keV and ≤ 0.925keV at 1.33MeV and 122keV, respectively, with a relative efficiency of 35%. The germanium crystal was located within a lead shield for the reduction of the environmental background. The detector is connected to preamplifier, main amplifier, analogue to digital converted (ADC) and multichannel analyzer. The system was calibrated for energy using standard point sources (60Co, 137Cs), and calibrated for efficiency using standard QCYB41 [4,12]. Every sample was placed in face to face geometry the detector for 10 to 24hour for (226Ra, 232Th and 40K) concentrations measurements. Prior to sampling counting, background were taken normally every week under the same condition of sample measurement. The spectra were analyzed by the computer software program Canberra's Genie2000 Canberra Industries, Inc, USA) for the calculation of natural radioactivity. The radioactivity concentration of 226Ra was determined from the photo peaks of 214Pb (295.22, 351.93keV) and 214Bi (609.31, 1120.29, 1764.49keV). The concentration of 232Th was determined from the photo peaks of 228Ac (911.2, 968.97keV), 212Pb (238.63keV), and 208Ti (583.19, 2614keV), while 40K was determined from the 1460.8keV photo peak [4,12].

2.4. Measuring activity of radionuclides:

The activity concentration of each isotope has been calculated by using the following equation:

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

Where Npis the number of count in a given peak area corrected for background peaks of a peak at energy E, ε (Eγ) the detection efficiency at energy E, tc is the counting life time, Iγ (Eγ) the number of gammas per disintegration of this nuclide for a transition at energy E, and M the mass in kg of the measured samples [10].

3. Results and Discussion

3.1. Activity Concentrations of the radionuclides:

The results of the present work are summarized in Table (1) and shown in figure (2), it can be noticed that the highest value of specific activity concentration of (^{226}Ra) was found in T7 Daar-Saad region which was equal to (0.525±0.29Bq/L), while the lowest value of specific activity concentration of (^{226}Ra) was found in T11 Aden Assughra region which was equal to (0.017±0.006Bq/L) with an average value of (0.228±0.13Bq/L).The highest value of specific activity concentration of (^{232}Th) was found in T5 Khor-makser region which was equal to (0.319±0.18/L), while the lowest value of specific activity concentration of (^{232}Th) was found in T11 Aden Assughra region which was equal to (0.009±0.001Bq/L)with an average value of (0.129±0.089Bq/L). The highest value of specific activity concentration of (^{40}K) was found in T2 Al-Ma"allah region which was equal to (0.4±0.26Bq/L), while the lowest value of specific activity concentration of (^{40}K) was found in T11 Aden Assughra region which was equal to (0.027±0.004Bq/L), with an average value of (0.141±0.021Bq/L). It is noted that, the ^{226}Ra, ^{232}Th and ^{40}K concentrations are varying in small and narrow range, due to that, the original sources of the measured tap waters is ground water wells, in different places in Aden, governorate. In addition to that this similarity comes from that the study area has the same geological properties and the natural radioactivity of the subsoil in Aden governorate area is generally low. Reference values for ^{226}Ra and ^{232}Th activity concentrations in tap drinking water are lower than value of world limit 1Bq/L according to UNSCEAR 2000 "United Nations Scientific Committee on the Effects of Atomic Radiation" and WHO [13,14]. The activity concentrations radionuclide of ^{226}Ra were found to be slightly higher (but not significant) than that of ^{232}Th, which may be attributed to the fact that ^{226}Ra is more soluble than ^{232}Th in water as shown in figure (3).

Table 1: Symbol, location name and Coordinates, for tap water samples sites in Aden governorate

Sample code	Name of the Site	Coordinates		^{226}Ra	^{232}Th	^{40}K
		Latitude (N)	Longitude (E)			
T1	At-Tawahi	12°46'30"	44°59'12"	0.064±0.008	0.061±0.007	ND
T2	Al-Ma"allah	12°47'29"	45°00'15"	0.467±0.26	0.292±0.26	0.4±0.26
T3	Crutter	12°46'42"	45°02'09"	0.119±0.035	0.077±0.010	0.044±0.003
T4	Crutter	12°46'41"	45°02'47"	0.058±0.006	0.032±0.002	0.063±0.009
T5	Khor-Makser	12°46'30"	44°59'12"	0.328±0.109	0.319±0.18	ND
T6	Ash Shaykh"Uthman	12°47'29"	45°00'15"	0.519±0.164	0.234±0.08	ND
T7	Dar-Saad	12°46'42"	45°02'09"	0.525±0.29	0.097±0.010	0.281±0.010
T8	Dar-Saad	12°46'41"	45°02'47"	0.135±0.037	0.124±0.040	ND
T9	Al-Mansoura	12°48'43"	45°02'14"	0.076±0.008	0.049±0.003	ND
T10	Aden Assughra	12°52'32"	44°59'12"	0.202±0.055	0.127±0.012	ND
T11	Aden Assughra	12°52'32"	44°59'10"	0.017±0.006	0.009±0.001	0.027±0.004
Maximum				0.525±0.29	0.319±0.18	0.4±0.26
Minimum				0.017±0.006	0.009±0.001	0.027±0.004
Mean				0.228±0.13	0.129±0.089	0.141±0.021

ND means not detect.

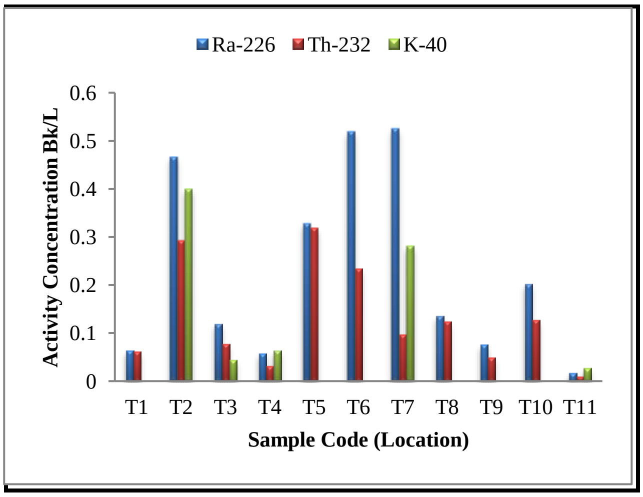

Fig. 2: ^{226}Ra, ^{232}Th, and ^{40} K Activity concentrations in (tap) drinking water Samples.

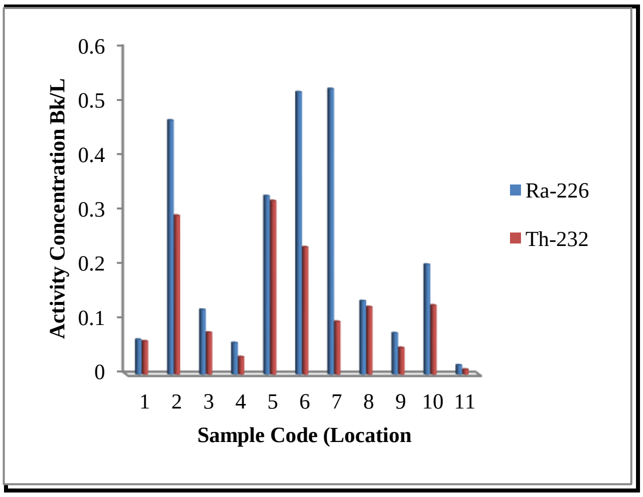

Fig. 3: Compare between^{226}Ra, ^{232}Th, Activity concentrations in (tap) drinking water Samples.

3.2. Inhalation exposure through ingestion of drinking water:

The ingestion of the radionuclides depends on the consumption rates of food and water and on radionuclide concentrations (UNSCEAR, 2008). Annual effective dose (AED) due to the ingestion of the tap drinking water samples was estimated to evaluate the radiological hazards members of the public (infant, children and adult). 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 total annual effective doses AED_{dw} (μSv/y) was estimated using the activity concentrations of the radionuclides, dose coefficients and annual water consumption according to the equation introduced by EPA (Environmental Protection Agency, USA) and by Meltem and Gursel [15,16].

$$\mathbf{AED_{dw} = A_w \times IR_w \times ID_F} \qquad (2)$$

Where:

AED_{dw} the total annual effective dose (μSv/y), A_w is the radionuclide activity concentration (Bq/L), IR_w intake of water for person in one year and IDF the effective dose conversion factor (mSv/Bq). Doses were estimated by considering a consumption rate (150, 350 and 500L/year) for infants, children and adults, respectively. The effective dose equivalent conversion factors ID_F for ^{226}Ra, ^{232}Th and ^{40}K, respectively, are (9.6×10^{-7}, 4.5×10^{-7} and 5×10^{-9} $SvBq^{-1}$) for infants, (8×10^{-7}, 2.9×10^{-7} and 5×10^{-9}

$SvBq^{-1}$) for children (2.8×10^{-7}, 2.3×10^{-7} and 5×10^{-9}SvB/q) for adults as reported by ICRP, International Atomic Energy Agency (IAEA) and WHO [17, 18]. Table (2) shows the calculated annual effective dose for different age groups infants, children and adults, considering only the ingestion from ^{226}Ra and ^{232}Th.The obtained values of the total annual effective dose of tap water samples for infants, children and adults were ranged from (3.05 to 98.77), (5.67 to 178.16) and (3.41 to 119.08) with average values of (42.65, 78.62 and 48.62μSv/y) for infants, children and adults respectively. The annual effective dose values in the investigated tap drinking water samples, for the different age groups "infants, children and adults ", are presented in figure (3).

From Table (2) and figure (4), it is noted that, the doses received due to the ingestion of radionuclide's in tap water by children are higher than that received by infants and adults and the main dose contribution of these waters is caused by ^{226}Ra. Thus the age group at risk is children because of their intensive bone growth and action should be taken to restrict their intake. These values can be considered as important contributors to the daily incorporation of radionuclides by ingestion, and it's also relevant when compared to the recommended reference level for the effective dose published by IAEA. The results showed that the annual effective dose of ingestion of these drinking water samples for the different age groups "infants, children and adults "is lower than the recommended value of (260, 200, and 100)μSvyear^{-1} for ^{226}Ra, ^{232}Th, and ^{40}K, respectively, as reported by WHO [13,14]. The doses received in all examination regions by children were higher than those received by infants and adults, and doses received by adults were higher than those consumed by infants.

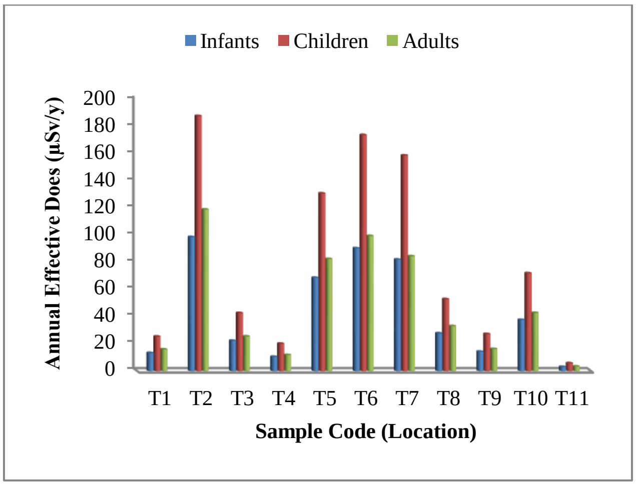

Fig. 4: The annual effective doses considering the ingestion of ^{226}Ra and ^{232}Th radionuclides for different age groups in tap water.

Table 2: Estimates of annual effective doses μSvyear^{-1} due to ingestion of ^{226}Ra and ^{232}Th for different age groups.

Sample Code	Ra-226			Th-232			Total		
	Infants	Children	Adults	Infants	Children	Adults	Infants	Children	Adults
T1	9.22	17.92	8.96	4.12	7.47	7.01	13.33	24.11	15.97
T2	67.25	130.76	65.38	31.52	57.21	53.70	98.77	178.16	119.08
T3	17.14	33.32	16.66	5.20	9.43	8.85	22.33	41.13	25.51
T4	8.35	16.24	8.12	2.16	3.92	3.68	10.51	19.49	11.80
T5	47.23	91.84	45.92	21.53	39.08	36.68	68.76	124.22	82.60
T6	74.74	145.32	72.66	15.79	28.66	26.91	90.53	169.07	99.57
T7	75.60	147	73.50	6.55	11.88	11.15	82.15	156.84	84.65
T8	19.44	37.8	18.9	8.37	15.19	14.26	27.81	50.39	33.16
T9	10.94	21.28	10.64	3.31	6.00	5.63	14.25	26.25	16.27
T10	29.09	56.56	28.28	8.57	15.56	14.605	37.66	69.45	42.88
T11	2.45	4.76	2.38	0.61	1.10	1.03	3.05	5.67	3.41
Mean	32.86	63.90	31.94	9.79	17.77	16.68	42.65	78.62	48.62
Maximum	75.60	147.00	73.50	31.52	57.21	53.70	98.77	178.16	119.08
Minimum	2.45	4.76	2.38	0.61	1.10	1.03	3.05	5.67	3.41

3.3. Life-time cancer risk ($ELCR$):

The excess life-time cancer risk ($ELCR$) was estimated from annual effective dose equivalent using the equation [19]:

$$ELCR\ (\mathrm{R}) = AEDE \times DL \times RF \qquad (3)$$

Where: DL and RF 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 for the public for random effects, for low-level radiations [20,21].

3.4. Risk Based on the Radium Isotopes:

The annual effective doses (μSvyear^{-1}) for adults from radium isotopes and the associated cancer risk, due to water consumption in the examined areas of Aden governorate, were determined. The annual effective dose decided from radium isotopes ranged from 2.38μSvyear^{-1}to 73.50μSvyear^{-1} with a mean value of 31.94μSvyear^{-1} and from 1.03μSvyear^{-1} to 53.70μSvyear^{-1} with a mean value 16.68μSvyear^{-1} for ^{226}Ra and ^{232}Th respectively. The excess life-time cancer risk ($ELCR$) estimated from annual effective dose was found to be ranged from 0.81×10^{-5} to 25.72×10^{-5}, with an average estimation of 11.19×10^{-5} for ^{226}Ra and from 0.38×10^{-5} to 12.84×10^{-5} with an average estimation of 5.20×10^{-5} for ^{232}Th indicating that within one million adult population who consume tap water with T1-T11, approximately 13 to 386 individuals are probably faced with the risk of cancer. The estimations of individuals with cancer risk were found to be lower than 4800.This number was found to match the prediction from UNSCEAR and set apart from the threshold value. However, if the estimated cancer risk was found exceed or be close to the threshold value, proper attention and remedial actions were required in the contaminated areas [22,19]. The total ELCR ranges from 1.19×10^{-5} and 34.85×10^{-5}, with an average value of 16.39×10^{-5}. It clear that the ELCR for water samples in Aden Governorate is lower than the worldwide limit of 145×10^{-5} in drinking water that was disseminated by USEPA [23]. The behavior of ELCR in samples is shown in Figure (5).

4.4. Comparison of results with similar in other countries:

Table (5) summarized the values of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations in other countries and those from the present study. As can be seen from table (4) and figure (6): ^{226}Ra activity concentrations were found in values higher than that reported by Alfatih et al., 2008 in Sudan [25], Violeta et al., 2020, in Romania [16], Nuraddeen, 2016 in Malaysia[29] and lower than that reported by Ajayi, 2012 in Nigeria[26], Eric, 2014 in Ghana[28], Alaboodi et.al., 2020 in Iraq[1], and by Khoirul et al., 2020 in Malaysia[19]. ^{232}Th activity concentrations were found in values higher than that reported by Alfatih et al., 2008 in Sudan [25], Violeta et al., 2020, in Romania [16], Nuraddeen, 2016 in Malaysia [28] and H Saad and N Aref 2021 in Iraq [10] and lower than that reported by Ajayi, (2012) in Nigeria [25], Eric, 2014 in Ghana [26], Alaboodi et.al., 2020 in Iraq [1] and Wiseman, 2015, in Ghana[27]. Whereas ^{40}K activity concentrations were found in values higher than that reported by Ajayi, (2012) in Nigeria[26], Eric, 2014 in Ghana[28], Alaboodi et.al., 2020 in Iraq [1] , Wiseman, 2015 in Ghana and H Saad and N Aref 2021 in Iraq [10].

Table 3: The values of annual effective doses (μSvyear^{-1}) for adults and the Radiological risk of radium isotopes for water samples.

Sample Code	Annual Effective Dose (μSv/y) (μSv year^{-1})		Radiological Risk ×10^{-5} ELCR (R)		
	^{226}Ra	^{232}Th	^{226}Ra	^{232}Th	Total
T1	8.96	7.015	3.11	2.46	5.57
T2	65.38	53.70	22.90	11.75	34.65
T3	16.66	8.85	5.83	3.10	8.93
T4	8.12	3.68	2.86	1.29	4.15
T5	45.92	36.68	16.07	12.84	28.91
T6	72.66	26.91	25.43	9.42	34.85
T7	73.50	11.15	25.72	3.91	29.63
T8	18.9	14.26	6.62	4.99	11.61
T9	10.64	5.63	3.74	1.98	5.72
T10	28.28	14.605	9.89	5.11	15.0
T11	2.38	1.03	0.81	0.38	1.19
Mean	31.94	16.68	11.19	5.20	16.38
Maximum	73.50	53.70	25.72	12.84	34.85
Minimum	2.38	1.03	0.81	0.381	1.19

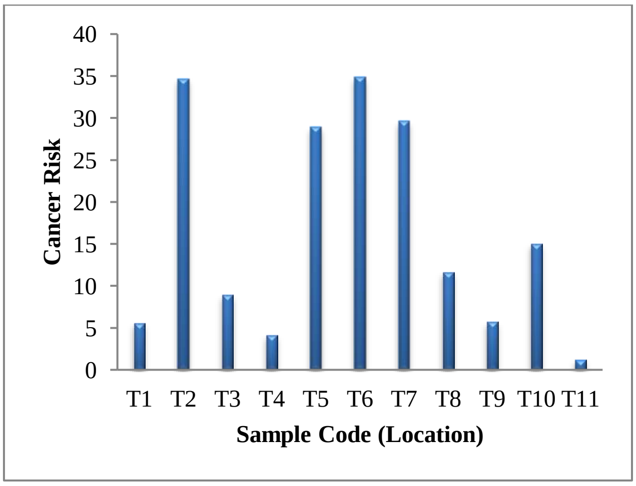

Fig. 5: Excess Lifetime Cancer Risk of Tap Water Samples.

Table 4: The activity concentration in Bq/L of Tap water samples in comparison with other countries.

Countries	Activity Concentration (Bq/L)			Reference
	^{226}Ra	^{232}Th	^{40}K	
Yemen	0.288±0.16	0.129±0.089	0. 141±0.021	Present work
Sudan	0.0085±0.016	0.0001±0.004	ND	[25]
Romania	0.008 ± 0.002	0.03 ± 0.009	ND	[16]
Nigeria	1.52±0.69	2.28±0.57	22.05±8.09	[26]
Ghana	0.530±0.29	1.41±0.08	11.89±0.74	[27]
Ghana	0.917 ± 0.61	0.681 ± 0.66	1.005 ± 0.61	[28]
Malaysia	0.013±0.003	0.004±0.001	1.12±7.5	[9]
Iraq	21.92±8.04	1.42±0.64	34.54±12.67	[10]
Iraq	1.84±0.39	1.31±0.33	9.07±1.32	[1]
Malaysia	1.51 ± 0.30	0.17 ± 0.09	7.67 ± 3.07	[19]

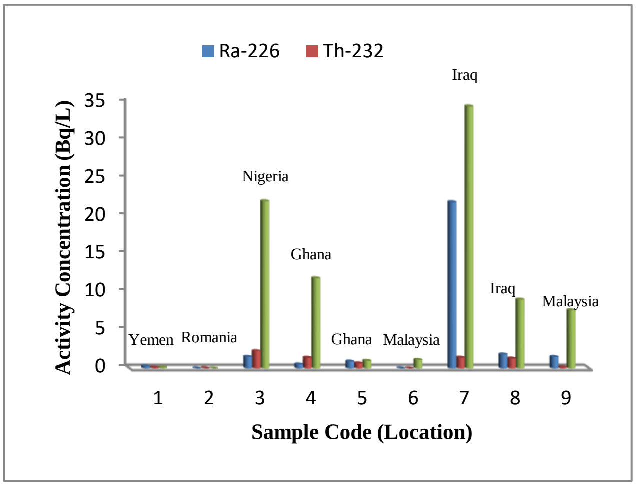

Fig. 6: Comparison of the resulted activity concentration with those of other countries.

4. Conclusion

A total of 11 Tap water samples were obtained from the water networks in dwellings from different locations in Aden Governorate, Yemen. The natural radioactivity levels in the water samples were determined using a hyper pure germanium detector (HPGE). The results have shown that, the specific activity, for ^{226}Ra was ranged from (0.017±0.006Bq/L) in Aden Assughra region to (0.525±0.29Bq/L) in Daar-Saad region, for ^{232}Th the specific activity was ranged from (0.009±0.001Bq/L) in Aden Assughra region to (0.319±0.18Bq/L) in Khor-makser region, for ^{40}K the specific activity was ranged from (0.027±0.004Bq/L) in Aden Assughra region to (0.4±0.26Bq/L) in (Al-Ma"allah) region, with an average values of (0.228±0.13Bq/L), (0.129±0.089Bq/L), (0.141±0.021Bq/L**,** for ^{238}U, ^{232}Th and ^{40}K, respectively.

The total annual effective doses and the estimated cancer risk show that the radionuclides under this study do not pose any significant health risks to the public. The data obtained in this study are considered benchmarks, which can be used to survey possible future changes. They should give a better than average example in setting measures for water quality in the country.

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مقالة بحثية

قياس النشاط الاشعاعي الطبيعي لعينات من مياه الشرب من مناطق مختلفة في محافظة عدن، اليمن

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المُلخّص

تمَّ قياس النشاط الاشعاعي الطبيعي لاحدى عشر عينة من مياه الشرب من الحنفية من مناطق مختلفة في منازل مديريات محافظة عدن باستخدام كاشف الجرمانيوم عالي النقاوة (HPGe). اظهرت النتائج ان اعلى تركيز للراديوم-226 لعينات مياه الشرب من الحنفية وجدت في العينة T7 في مديرية دار سعد والتي تساوي Bq/L(0.525±0.29) بينما اقل قيمة وجدت في العينة T11 في مديرية عدن الصغرى والتي تساوي Bq/L(0.017±0.0060) بمعدل تركيز للراديوم-226 يساوي Bq/L(0.228±0.13). فيما اطهرت النتائج ان اعلى تركيز للثوريوم -232 لعينات مياه الشرب من الحنفية هي في العينة T5 في مديرية خورمكسر والتي تساوي Bq/L(0.319±0.18) بينما اقل قيمة وجدت في العينة T11 في مديرية عدن الصغرى والتي تساوي Bq/L(0.009±0.0010) بمعدل تركيز للثوريوم -232 يساوي Bq/L(0.129±0.089). كما اظهرت النتائج ان اعلى تركيز للبوتاسيوم-40 لعينات مياه الشرب من الحنفية وجدت في العينة T2 في مديرية المعلا والتي تساوي Bq/L(0.40±0.26) بينما اقل قيمة وجدت في العينة T11 في مديرية عدن الصغرى والتي تساوي Bq/L(0.027±0.0040) بمعدل تركيز للبوتاسيوم-40 يساوي Bq/L(0.141±0.021). حسبت الجرعة السنوية المؤثرة الممتصة الناتجة عن استهلاك مياه الشرب من الحنفية للفئات العمرية الثلاث الرضع، الاطفال والبالغين، وجد انها تقع في المدى (3.05 to 98.77µSv/y), (5.67to178.16µSv/y), (3.41to119.08µSv/y) بمعدل يساوي48.62µSv/y,87.62µSv/y, 42.65µSv/y, للفئات العمرية الثلاث الرضع, الاطفال والبالغين على التوالي. هذه القيم للجرعة السنوية المؤثرة الناتجة عن استهلاك المياه تعد قليلة مقارنة مع الحد الموصى به عالميا" من جانب منظمة الصحة العالمية وكذلك منظمة EU Council والتي تساوي ($260\mu Sv\ year^{-1}$and $200\mu Sv\ year^{-1}$) لكل من الراديوم -226 والثوريوم-232 لمياه الشرب من الحنفية. فيما حسب معامل خطورة السرطان ELCR وجد انه يقع في المدى (1.19×10^{-5} to 38.56×10^{-5}) بمعدل يساوي (16.39×10^{-5}). من الواضح ان معامل خطورة السرطان في عينات مياه الشرب من الحنفية اقل من القيمة الموصى بها عالميا" والتي تساوي (145×10^{-5}) بشكل عام اظهرت النتائج ان تركيز الراديوم-226، الثوريوم -232 وكذلك البوتاسيوم-40 في عينات مياه الشرب من الحنفية قيد الدراسة اقل من القيمة العليا المسموح بها والموصى بها من قبل الوكالة الامريكية لحماية البئية (USEPA, 2012) والتي تساوي (11.1Bq/L) ولاتشكل المياه من الحنفية اي خطورة على الحياة البشرية ولايوجد اي ضرر على المياة المستخدمة للشرب من الحنفية.

الكلمات المفتاحية: مياه الشرب من الحنفية، الفعالية الاشعاعية، الجرعة الممتصة السنوية، محافظة عدن، معامل خطورة السرطان.

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