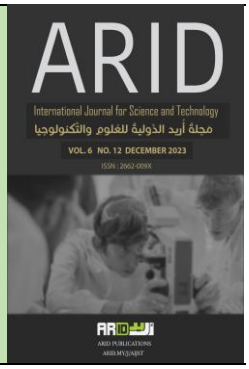
ARID Journals

ARID International Journal for Science and Technology (AIJST)
ISSN: 2662-009X

Journal home page: http://arid.my/j/aijst



مَجلةُ أُريد الدَّوليةُ للعُلومِ والتِّكنولوجيا

المجلد 6 ، العدد 12 ،كانون الأول 2023 م

MEASUREMENT OF RADON GAS CONCENTRATION IN WATER SAMPLES IN ADEN GOVERNORATE BY USING NUCLEAR TRACK DETECTOR (CR-39)

Fuad Abdo AS-Subaihi[1], Abdulazize Omer Bazohair[2], Sultan Abdulrab AS-Subaihi [3].

[1]Physics department, Faculty of Education-Sabir, Aden University. Yemen.
[2]Physics department, Faculty of Education-Makalla, Hadhramout University, Yemen.
[3]Physics department, Faculty of Science-Aden, Aden University. Yemen.

قياس تركيز غاز الرادون لعينات من المياه من محافظة عدن باستخدام كاشف الأثر النووي CR-39

فؤاد عبده أحمد الصبيحي [1] * ,عبدالعزيز عمر بازهير[2], سلطان عبدالرب قايد[3]

[1] قسم الفيزياء - كلية التربية - صبر- جامعة عدن,اليمن
[2] قسم الفيزياء - كلية التربية -المكلا- جامعة حضرموت, اليمن
[3] قسم الفيزياء - كلية العلوم - عدن - جامعة عدن, اليمن

fuadassubaihi023@gmail.com
arid.my/0007-5257
https://doi.org/10.36772/arid.aijst.2023.6124

ARTICLE INFO
Article history:
Received 05-11-2023
Received in revised form 22-11-2023
Accepted 28-11-2023
Available online 15/12-2023
https://doi.org/10.36772/arid.aijst.2023.6124

ABSTRACT

Fifteen samples of natural water were brought from different sources: projects of tap water, Ground water, in Aden governorate. Long-term technique for alpha particles emission with solid state nuclear track detector (SSNTD) CR-39 detectors has been used to determine the concentrations of radon (^{222}Rn). The results of measurements show that the highest value of radon gas concentration in tap water was found in T4 (Crutter) region, which was equal to (0.060±0.0021) Bq/L, while the lowest value of radon gas concentration was found in T10 (Little Aden) region, which equal to (0.044±0.0015) Bq/L, with an average value of (0.051±0.0020)Bq/L. The highest value of radon gas concentration in ground water samples was found in G1 (Beer Ahmed) region, which equal to (0.106±0.0030) Bq/L, while the lowest value of radon gas concentration was found in G4 (Beer Nasser) region, which equal to (0.085±0.0020)Bq/L, with an average value of (0.097±0.0020)Bq/L. The highest value of annual effective dose in tap water samples was found in T4 region, which was equal to (0.219μSv/y), while the lowest value of annual effective dose was found in T10 region, which was equal to (0.161μSv/y), with an average value of (0.186μSv/y). The highest value of annual effective dose in ground water samples was found in G1 region, which was equal to (1.29μSv/y), while the lowest value of annual effective dose was found in G4 region, which was equal to (1.04μSv/y), with an average value of (1.19μSv/y). These values are regarded less in comparison with the allowed normal limit which is about 100μsv.y^{-1} for drinking water. In general radon gas concentrations in tap and ground water samples were less than the recommended value (11.1Bq/L) given by (USEPA, 2012). There for tap and Ground water in all the studied sites in Aden Governorate is safe as for as radon concentration, and there will be no risk on the human being life.

***Key Words*:** Tap water, Radon Concentration, Nuclear Track Detector CR-39, Annual Absorbed Dose**,** Little Aden.

المُلخّص

تمَّ قياس تركيز غاز الرادون-222 في مياه الشرب من الحنفية ومياه الآبار المغذية لشبكة مياه الشرب من الحنفية في محافظة عدن. أظهرت النتائج إن أعلى تركيز لغاز الرادون لعينات مياه الشرب من الحنفية وجد في العينة T4 في مدينة كريتر والذي يساوي (0.060±0.0021Bq/L) بينما أقل قيمة وجدت في العينة T10 في مدينة عدن الصغرى والذي تساوي (0.044±0.0015Bq/L) بمعدل تركيز لغاز الرادون-222 يساوي (0.051±0.0020Bq/L). حسبت الجرعة السنوية المؤثرة الناتجة عن استهلاك مياه الشرب من الحنفية، ووجد إن أعلى قيمة للجرعة السنوية المؤثرة في العينة T4 في مدينة كريتر والذي يساوي (0.219µSv/y) بينما أقل قيمة للجرعة السنوية المؤثرة وجدت في العينة T10 في مدينة عدن الصغرى والذي تساوي (0.161µSv/y) بمعدل سنوي يساوي للجرعة المؤثرة (0.186µSv/y). تمَّ قياس تركيز غاز الرادون-222 في مياه الآبار المغذية لشبكة مياه الشرب من الحنفية في محافظة عدن وأظهرت النتائج إن أعلى تركيز لغاز الرادون في مياه الآبار المغذية لشبكة مياه الشرب من الحنفية وجد في العينة G1 في منطقة بئر أحمد والذي تساوي (0.106±0.0030) بينما أقل قيمة وجدت في العينة G4 في منطقة بئر ناصر في محافظة لحج والذي تساوي (0.085±0.0020Bq/L) بمعدل تركيز لغاز الرادون-222 يساوي (0.097±0.0020Bq/L). حسبت الجرعة السنوية المؤثرة، الناتجة عن استهلاك مياه الآبار المغذية لشبكة مياه الشرب من الحنفية ووجد إن أعلى قيمة للجرعة السنوية المؤثرة في العينة G1 في منطقة بئر أحمد والذي يساوي (1.29µSv/y) بينما أقل قيمة للجرعة السنوية المؤثرة وجدت في العينة G4 في منطقة بئر ناصر في محافظة لحج والذي تساوي (1.04µSv/y) بمعدل سنوي يساوي للجرعة المؤثر (1.19µSv/y). هذه القيم للجرعة السنوية المؤثرة الناتجة عن استهلاك المياه تعد قليلة مقارنة مع الحد الموصى به عالميا" من جانب The World Health Organization and EU Council البالغ (100µSv/y) لمياه الشرب من الحنفية وكذلك مياه الآبار المغذية لها. بشكل عام أظهرت النتائج إن تركيز غاز الرادون في عينات مياه الشرب من الحنفية ومياه الآبار المغذية لها قيد الدراسة أقل من القيمة العليا المسموح بها والموصى بها من United States Environmental Protection Agency (USEPA, 2012) (11.1Bq/L) وإنه لا يشكل خطورة على الحياة البشرية.

الكلمات المفتاحية: مياه الحنفية, تركيز الرادون, كاشف الأثر CR-39, الجرعة الممتصة السنوية, عدن الصغرى.

1. Introduction

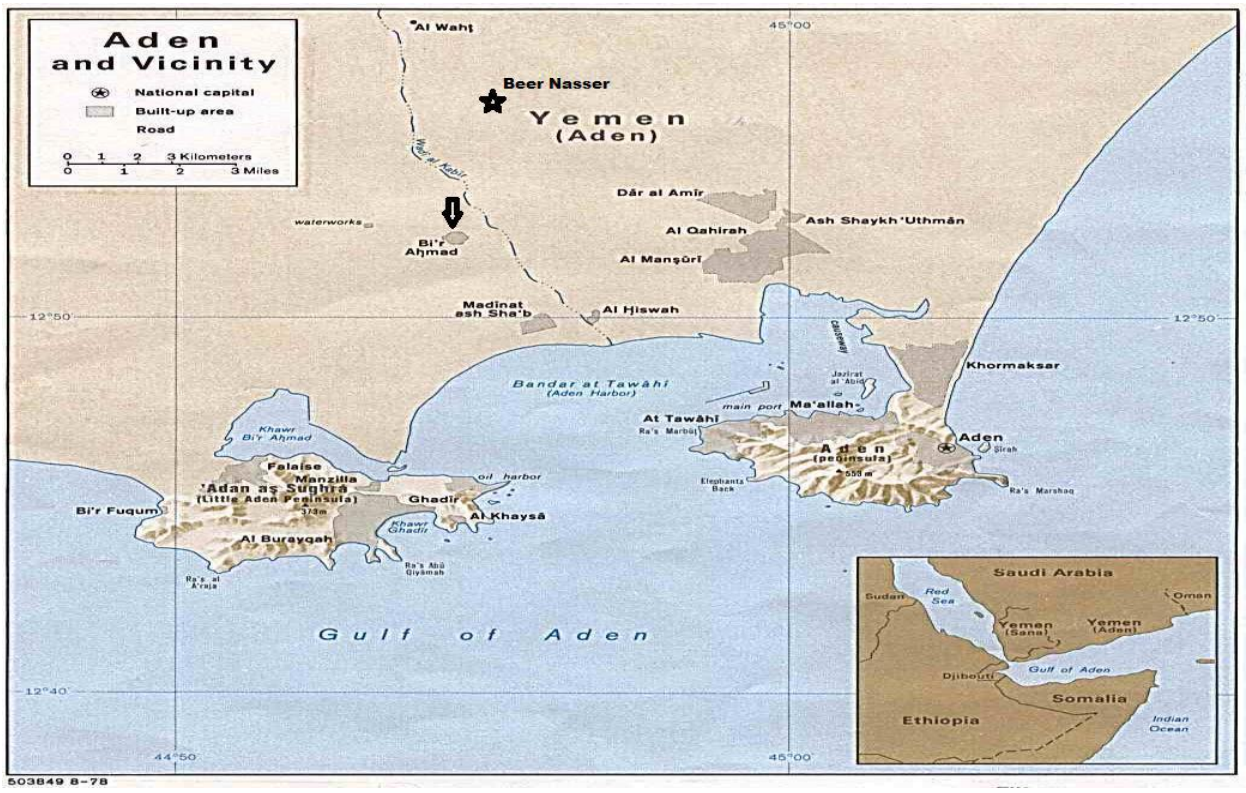
Radon (^{222}Rn) is a natural inert radioactive tasteless, colorless and odorless gas, whose density is about 7.5 times higher than that of air**.** It dissolves in water and can readily diffuse with gases and water vapor, thus building up significant concentrations**.** The physical half-life of radon is 3.825 days and half-elimination time from lungs 30 min. Radon ^{222}Rn, which is the daughter of uranium ^{238}U, represents the most important radon isotope**[1-3].** Radon has three isotopes, i.e., (i) Rn-219 or "actinon" is a part of U-235 decay chain. It has been never encountered in indoor air due to its short half-life (3.4 s). (ii) Rn-220 or "thoron" is a part of Thorium-232 decay chain; its half-life is more than actinon but <1 min (54 s). (iii) Rn-222 or familiar "radon" is a part of the U-238 decay chain. Its half-life is 3.8 days. Due to its longer half-life, it is detected in indoor air, outdoor air, soil gas, and water samples. Decay of the radon nucleus ^{222}Rn yields short-living daughters: polonium ^{218}Po, lead ^{214}Pb and bismuth ^{214}Bi **[4, 5].** The sources of Radon in water are; either from radioactive decay of dissolved Radium in water, or, from a direct release of Radon from minerals containing member of Uranium and Thorium decay series **[6].** Moreover, inhalation of radon gas that has been released from tap water which will contribute to the radon content of indoor air and, if inhaled, will result in a radiation dose to the lung? Long-term exposure to high concentrations of radon in indoor air increases the risk of lung cancer **[7].** In the present work, the passive technique using the solid state nuclear track detectors (SSNTDs) has been utilized to measure the radon concentration for tap water samples for selected regions sites in Aden governorate. CR-39 detector was used during the currently conducted study because of its simplicity and long-term integrated read out, high sensitivity to alpha-particle radiation ruggedness, availability and ease of handling. The principle of this technique is based on the production of tracks in the detector due to alpha particles emitted from radon and its progeny. After

exposure, the tracks are made visible by chemical etching and counted manually under the optical microscope. The measured track density is then converted into radon concentration **[5].**

2. Experimental Procedure

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 governorate. In fact, the study area is located inside Aden Governorate which is located in South of Yemen on the Gulf of Aden. 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 1and 2 show symbol and location name for the different studied regions (sites) in Aden governorate for tap and ground water samples.



Figure(1): Illustrates the areas under study

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

Sample code	Name of the Site	Coordinates	
		Latitude (N)	Longitude (E)
T1	Al-Tawahy	12°46’30"	44°59’12"
T2	Al-Mula	12°47’29"	45°00’15"
T3	Crutter	12°46’42"	45°02’09"
T4	Crutter	12°46’41"	45°02’47"
T5	Khormakser	12°48’43"	45°02’14"
T6	Shiek-Othaman	12°52’32"	44°59’12"
T7	Dar-Saad	12°52’32"	44°59’10"
T8	Dar-Saad	12°53’10"	44°58’56"
T9	Al-Mansoura	12°51’31"	44°58’56"
T10	Little Aden	12°50’14"	44°57’49"
T11	Little Aden	12°53’33"	44°54’03"

Table(2): Symbol, location name and Coordinates, for ground water samples sites in Aden governorate.

Sample code	Name of the Site	Coordinates	
		Latitude	Longitude (E)
G1	Beer Ahmed	12°58’9	44°69’41"
G2	Beer Ahmed	12°58’9	44°69’41"
G3	Beer Nasser	12°52’3	44°54’03"
G4	Beer Nasser	12°52’3	44°54’03"

2.2. The Detector

The experimental set-up is shown in Figure (2). Solid State Nuclear Track Detectors (SSNTD) with sheet thickness 500μm was used in this study, which is usually known as CR-39 which is sensitive to alpha particles of energy up to 40MeV. It was used as integrating detector of α-particles from ^{222}Rn and its daughter's nuclei. When a α-particle penetrates the detector, the particle causes damage along its path, the damage is then made visible by chemical etching. The etching produces a hole in the detector along the path of the particle. The hole can be easily observed in a light transmission microscope with a moderate magnification. **[5, 8]**

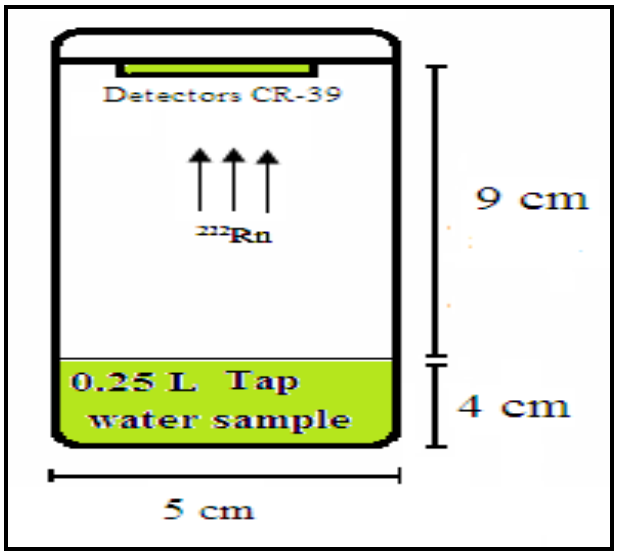


Figure (2): Sealed-cup technique used for water samples.

2.3. The Exposure

The Solid State Nuclear Track Detectors (SSNTD) was used for the measurements of Radon concentration in drinking tap water and ground water. (0.25 litter) in volume of tap water and ground samples were collected from different regions Aden governorate. The tap water samples were obtained from the water networks in sites houses and the ground water collected from the supplied source water networks wells. The radon gas concentrations in tap water samples were obtained using the sealed-cup (can) technique as shown in Figure 2. After the exposure time, CR-39 detectors were assembled from cans and chemically etched in NaOH solution 6.25 M at 70°C to enlarge and appear the alpha tracks through time equal 7 hours. After etching, the detectors were washed for 30 minutes with running cold water, then with distilled water and finally with a 50% water/alcohol solution. After a few minutes of drying in the air, the detectors were ready for track counting. The tracks were then counted using an optical microscope having a magnification of 400X.

2.4. Radon Concentration Measurement

The tracks density (ρ) of the samples is measured using the relationship (1) **[9]:**

$$\boldsymbol{\rho = \frac{\sum_{i=1}^{n} Ni}{nxA}} \qquad \textbf{(1)}$$

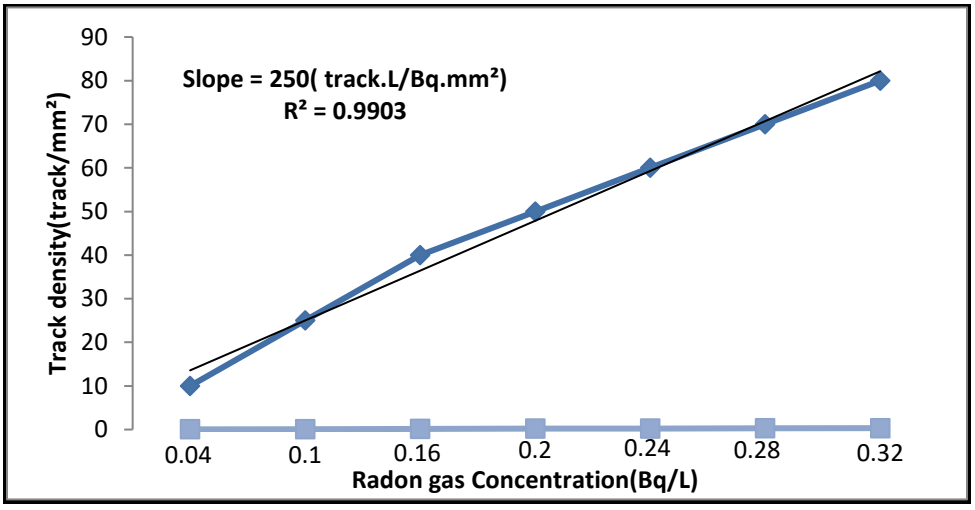
Where:

ρ: track density (track/mm^2), $\sum_{i=1}^{n} \mathrm{Ni} = \text{Total of the tracks}$, n = Total number of field counted, A = Area of the field of view. The radon gas concentration in water samples obtained by the comparison between track densities registered on the detectors of the samples and that of the standard water samples, using the relationship (2) **[10]:**

$$\boldsymbol{C_x(Bq.L^{-1}) = \frac{\rho_x . C_S}{\rho_S}} \qquad \textbf{(2)}$$

Where:

C_X: is the radon gas concentration in the unknown sample, CS: is the radon gas concentration in the standard sample, ρ_X: is the track density of the unknown sample (track/mm^2) and ρ_S: is the track density of the standard sample (track/mm^2). Figure 3. Shows the relation between radon gas concentration and track density in standard water samples.



Figure(3): Relation between radon gas concentration and track density in standard water samples.

2.5. The Annual Effective Dose in Water:

The annual effective dose (AED) of an individual consumer due to intake of radon from tap water in terms of (μSv/y) units was obtained using the relationship (3) **[11]:**

$$\mathbf{AED_W = C_{Rn}\, C_{RW} D_{CW}} \qquad \mathbf{(3)}$$

Where: C_{Rn} is the concentration of radon in the ingested tap water in (Bq/L), C_{Rw} is the annual intake (consumption rate) of water and it is equal to (730L/y) and D_{cw} is the dose conversion factor and it is equal to (5×10^{-9}Sv/Bq).

2.5.1. Determination of Radon Exhalation Rate in Water Samples

The radon exhalation rate (RER) or (E_A) of any sample is defined as the flux of radon released from the surface of material. The radon exhalation rate in terms of area (surface exhalation rate) in units of ($Bq.m^{-2}.h^{-1}$) can be obtained by using the relationship (4) **[12]:**

$$\mathbf{E_A\ (Bqm^{-2}d^{-1}) = \frac{CV\lambda_{Rn}}{A\left[T-\frac{1}{\lambda_{Rn}}\left(1-e^{-\lambda_{Rn}T}\right)\right]}} \qquad \mathbf{(4)}$$

Where:

E_A is the radon exhalation rate in terms of area, C: is the integrated radon exposure ($Bq.m^{-3}.h$). V: is the volume of air in the cup (m^3). λ: is the decay constant for ^{222}Rn (h^{-1}) = 0.1812 day^{-1} = 0.00755 h^{-1} h , A: is the surface area of the sample (m^2). T: is the exposure time (h) = 90 day = 2160 h.

2.5.2. Determination of Dissolved Radon Concentration

The dissolved radon concentration in tap water in terms of (Bq/L) units was obtained using the relationship (5) **[13]:**

$$\mathbf{C_d\ (Bq/L) = \left(\frac{C_{Rn}\lambda\, h\, T}{L}\right)} \qquad \mathbf{(5)}$$

Where:

C_{Rn}: is the concentration of radon in the ingested tap water in (Bq/L), λ: is the decay constant for ^{222}Rn (h^{-1}) = 0.1812 day^{-1} = 0.00755 h^{-1} h: is the distance from the surface of water to the detector (m) = 0.09 m, T: is the exposure time (h) =90 day = 2160 h, L: is the depth of the sample (m) = 0.04m.

3. Results and Discussion

Table 3 presents the radon gas concentrations in tap water samples for selected regions in Aden governorate obtained by using relationship (2). It can be noticed that, the highest average radon gas concentration in tap water samples was found in T4 (Crutter) region, which equal to (0.060±0.0021Bq/L), while the lowest average radon gas concentration was found in T10 (Little Aden) region, which equal to (0.044±0.0015Bq/L), with an average value of (0.051±0.0020Bq/L) as shown in figure 4. The highest value of annual effective dose in tap water samples was found in T4 region, which equal to (0.219μSv/y), while the lowest value of annual effective dose was found in T10 region, which equal to (0.161μSv/y), with an average value of (0.188μSv/y) as shown in Figure **5**.

Table(3): Sample location, radon gas concentration (C_{Rn}), annual effective dose (AED), dissolved radon concentration in tap water (Cd) and radon exhalation rate (RER) for tap water samples in Aden governorate.

Sample Code	Name of the Site	C_{Rn} ($Bq.L^{-1}$)	(AED) (μSv/y)	C_d ($Bq.L^{-1}$)	E_A ($\mu Bq/m^2h$)
T1	Al-Tawahy	0.056±0.0020	0.204	0.685	46.59
T2	Al-Mula	0.049±0.0017	0.179	0.599	40.76
T3	Crutter	0.055±0.0019	0.201	0.673	45.76
T4	Crutter	0.060±0.0021	0.219	0.734	49.91
T5	Khor-Makser	0.052±0.0018	0.190	0.636	43.26
T6	Shiek-	0.050±0.0017	0.182	0.611	41.59
T7	Dar-Saad	0.046±0.0016	0.168	0.563	38.27
T8	Dar-Saad	0.053±0.0018	0.193	0.648	44.09
T9	Al-Mansoura	0.047±0.0016	0.171	0.575	39.10
T10	Little Aden	0.044±0.0015	0.161	0.538	36.60
T11	Little Aden	0.054±0.0019	0.197	0.660	44.92
Mean		0.051±0.0020	0.188	0.629	42.80

Maximum	**0.060±0.0021**	**0.219**	**0.734**	**49.91**
Minimum	**0.044±0.0015**	**0.161**	**0.538**	**36.60**

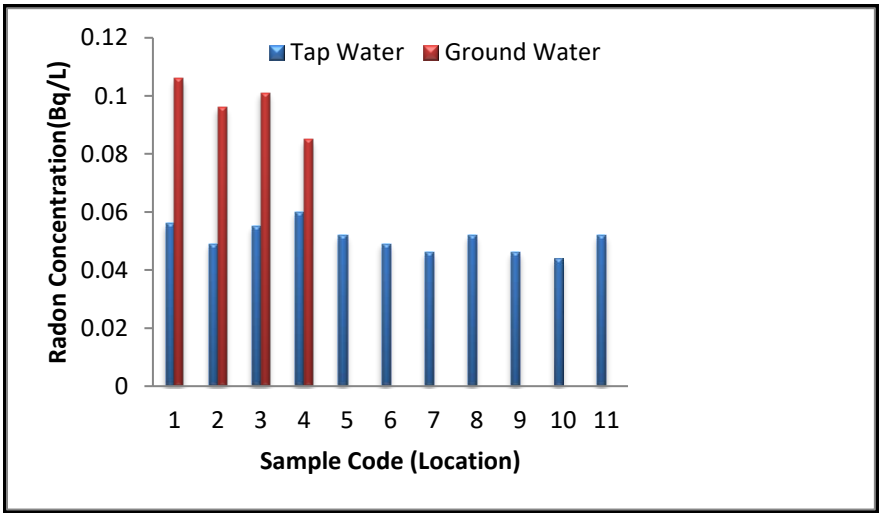


Figure (4): A histogram illustrating the change in radon concentration (C_{Rn}) in tap and ground water samples in Aden governorate.

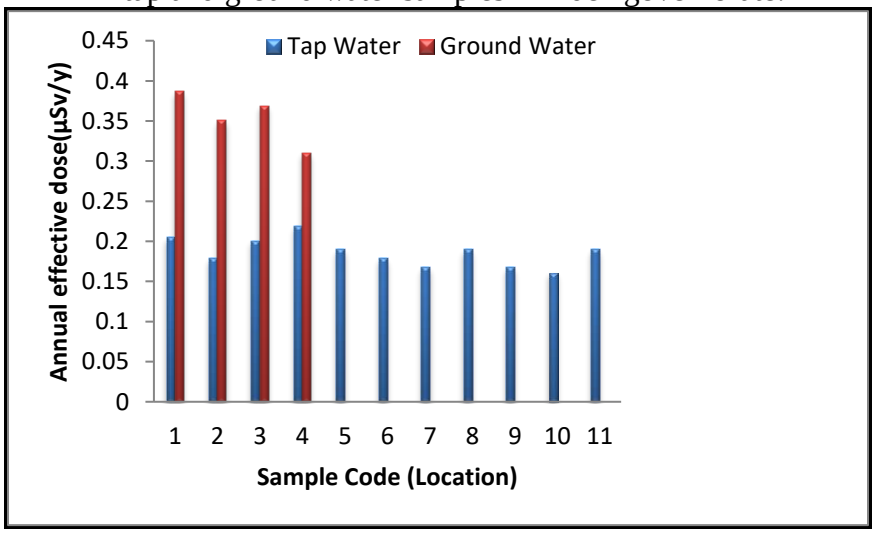


Figure (5): A histogram illustrating the change in annual effective dose (AED) in tap and ground water samples in Aden governorate.

The highest value of dissolved radon concentration in tap water samples (Cd) (obtained by using relation (6) was found in (T4 region) which was equal to ($0.734 Bq.l^{-1}$), while the lowest dissolved radon concentration in tap water samples was found in (T10 region) which was equal to

(0.538Bq/L), with an average value of (0.629Bq/L), as shown in Figure 6. The highest value of radon exhalation rate (RER) in tap water samples (obtained by using relationship (5) was found in (T4 region) which equal to (49.91μBq/m^2h), while the lowest value of radon exhalation rate in tap water samples was found in (T10 region) which equal to (36.60μBq/m^2h), with an average value of (42.80μBq/m^2h), as shown in Figure **7**.

Table 4 presents the radon gas concentrations in ground water samples for selected regions in Aden governorate obtained by using relationship (2). It can be noticed that, the highest average radon gas concentration in ground water samples was found in G1 (Beer Ahmed) region, which was equal to (0.106±0.0030Bq/L), while the lowest average radon gas concentration was found in G4 (Beer Nasser) region, which was equal to (0.085±0.0020Bq/L) with an average value of (0.097±0.0020Bq/L) as shown in figure **4**. The highest value of annual effective dose in ground water samples was found in G1 region, which was equal to (1.29μSv/y), while the lowest value of annual effective dose was found in G1 region, which was equal to (1.04μSv/y), with an average value of (1.19μSv/y) as shown in figure **5**. The highest value of dissolved radon concentration in ground water samples (Cd) (obtained by using relationship (6) was found in G1 region which was equal to (0.39Bq.l^{-1}), while the lowest dissolved radon concentration in ground water samples was found in (G4 region) which was equal to (0.31Bq.l^{-1}), with an average value of (0.35Bq.l^{-1}), as shown in Figure **6**.

The highest value of radon exhalation rate (RER) in ground water samples obtained by using relationship (5) was found in G1 region, which equal to (88.18μBq/m^2h), while the lowest value of radon exhalation rate in ground water samples was found in G4 region, which was equal to (70.71μBq/m^2h), with an average value of (80.70μBq/m^2h), as shown in Figure **7**.

Table(4): Sample location, radon gas concentration (C_{Rn}), annual effective dose (AED), dissolved radon concentration in ground water (Cd) and radon exhalation rate (RER) for ground water samples in Aden governorate.

Sample Code	Name of the Site	C_{Rn} (Bq.L^{-1})	(AED) (µSv/y)	C_d (Bq.L^{-1})	E_A (µBq/m^{2}h)
G1	Beer Ahmed	0.106±0.003	1.29	0.39	88.18
G2	Beer Ahmed	0.096±0.002	1.17	0.35	79.86
G3	Beer Nasser	0.101±0.003	1.23	0.37	84.02
G4	Beer Nasser	0.085±0.002	1.04	0.31	70.71
Mean		0.097±0.002	1.19	0.35	80.70
Maximum		0.106±0.003	1.29	0.39	88.18
Minimum		0.085±0.002	1.04	0.31	70.71

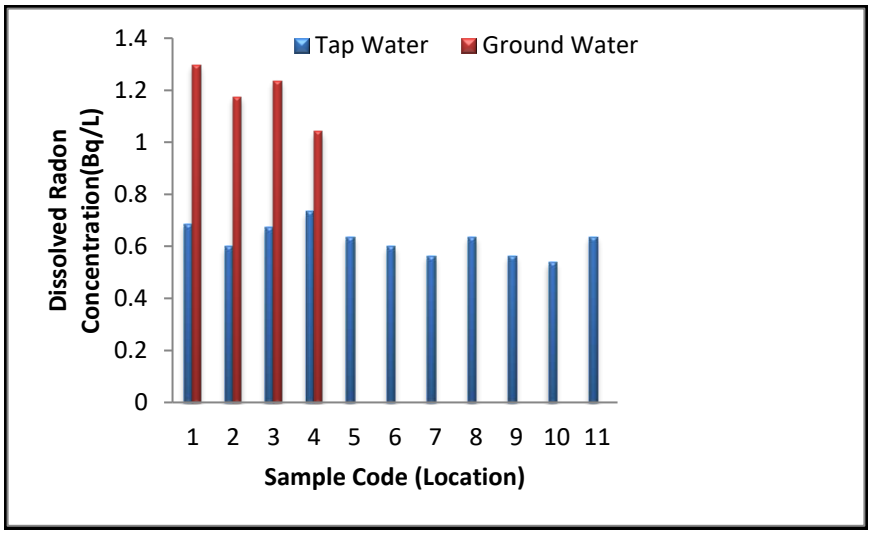


Figure (6): A histogram illustrating the change in dissolved radon concentration (Cd) in tap and ground water samples in Aden governorate.

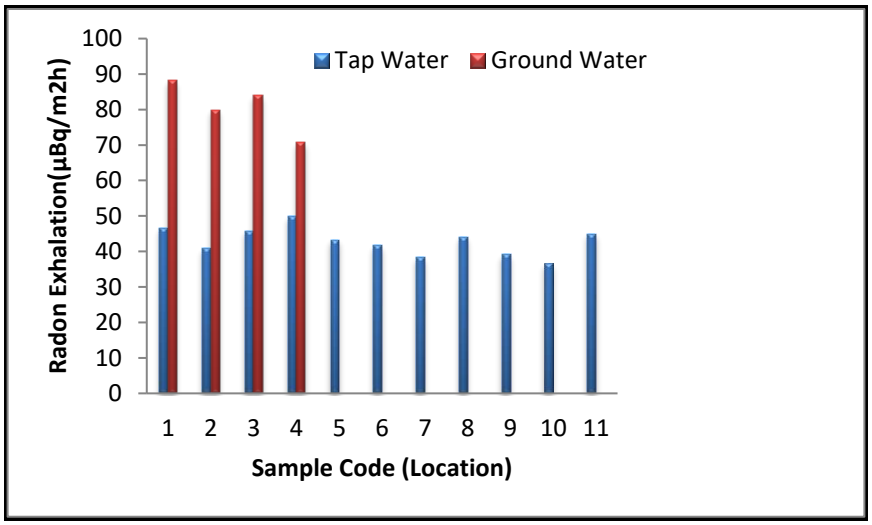


Figure (7): A histogram illustrating the change in radon exhalation rate (RER) in tap and ground water samples in Aden governorate.

Table **5** summarizes the values of ^{222}Rn activity concentrations in tap drinking water in other countries and those from the present study. As can be seen from table 5, the mean ^{222}Rn activity concentration values in tap drinking water are higher than that reported by Khalid, (2014) in Egypt**[16],** whereas ^{222}Rn activity concentrations were found in values lower than that reported by Ajayi,(2009) in Nigeria **[17]**, Wiseman, (2015) in Ghana [18], Laith et.al.,(2016) in Iraq **[5]**, Yan Shi et.al.,(2021) in China **[19]** and Giuseppe et al., (2021) in Italy **[20].** Table 6 summarizes the values of ^{222}Rn activity concentrations of ground water in some countries and those from the present study. As can be seen from table **7.** The mean values of ^{222}Rn activity concentrations in the present work are lower than that reported by Alabdula'aly, (2014) **[21]**, for ground water within, Saudi Arabia, Abdurabu et al., (2016) **[23]**, for ground water within, Yemen, Asare et al., (2018) **[24]** for ground water within Ghana, Alaboodi et al., (2020) **[26]**, for ground water within Iraq, Shu'aibu et al., (2021) **[27]** for ground water within Nigeria and Kumar et al., (2016) **[28]** for ground water within, India.

The present results for Aden governorate have shown that the radon gas concentration in all tap and ground water samples were found to be below the allowed limit value which was equal to (11.1Bq/L) **[14]**. Moreover, the annual effective doses in all studied samples were found to be below the allowed limit value (100μSv/y) **[15]**.

Table(5): Comparison of radon concentration in tap drinking water with those reported by other researchers.

Countries	^{222}Rn Activity Concentration (Bq/L)			References
	Maximum	Minimum	Mean	
Yemen	0.060±0.002	0.044±0.002	0.051±0.002	Present work
Egypt	0.118±0.003	0.006±0.0005	0.049±0.003	Khaled,2014 [16]
Nigeria	0.820±0.04	0.325±0.02	0.325±0.02	Ajayi,2009 [17]
Ghana	1.701	0.015	0.913 ±0.61	Wiseman, 2015 [18]
Iraq	0.190±0.01	0.073±0.01	0.135±0.03	Nada et.al., 2015 [2]
Iraq	0.820±0.04	0.325±0.02	0.563±0.12	Laith et.al.,2016 [5]
China	0.46±0.30	0.05–±0.0016	0.24 ±0.10	Yan Shi et.al.,2021 [19]
Italy	0.43 0.03	0.030 0.004	0.33± 0.09	Giuseppe et al., 2021 [20]

Table(6): Comparison of radon concentration in groundwater with those reported by other Researchers.

Countries	^{222}Rn Activity Concentration			References
	Maximum	Minimu	Mean	
Yemen	0.106	0.085	0.097	Present work
Saudi Arabia	40.9	0.06	5.34	Alabdula'aly, 2014 [21]
Saudi Arabia	9.15	0.76	3.56	Wedad et al., 2015 [22]
Yemen	896	1.0	226.4	Abdurabu et al., 2016 [23]
Ghana	41.26	1.0	10.97	Asare et al., 2018 [24]
China	31.31	1.29	10.47	Tan et al., 2019 [25]
Iraq	0.355	0.035	0.712	Alaboodi et al., 2020 [26]

Nigeria	**82.89**	**4.92**	**38.3**	**Shu'aibu et al., 2021 [27]**
India	**11.20**	**00.53**	**03.75**	**Kumar et al., 2016 [28]**

Therefore, the tap and ground water in all the studied regions in Aden governorate is safe as far as radon concentration is concerned. It is interesting to mention that all of the present results concerning the radon gas concentrations and dissolved radon gas concentrations for tap and ground water samples in all regions in Aden governorate were obtained for the first time.

5. Conclusions

The highest average radon gas concentration in tap water samples was found in T4 (Crutter) region, which was equal to (0.060±0.0021Bq/L), while the lowest average radon gas concentration was found in T10 (Little Aden) region, which was equal to (0.044±0.0015Bq/L), with an average value of (0.051±0.0020Bq/L). The highest value of radon gas concentration in ground samples was found in G1 (Beer Ahmed) region, which was equal to (0.106±0.0030), while the lowest value of radon gas concentration was found in G4 (Beer Nasser) region, which was equal to (0.085±0.0020), with an average value of (0.097±0.0020). The radon gas concentration in tap and ground water samples were found to be below the allowed limit value of (11.1Bq/L) given by (USEPA, 2012), and there will be no risk on the human being life.

Conflicts of Interest: The authors declare no conflict of interest.

List OF Abbreviations:

SSNTD Solid-State Nuclear Track Detector
ρ: track density (track/mm^2)
$\sum_{i=1}^{n} Ni$ = Total of the tracks
C_X Radon Gas Concentration in unknown Sample
C_S Radon Gas Concentration in Standard Sample
ρ_X Radon Gas Concentration in unknown Sample
ρ_S Track Density in Standard Sample
AED Annual Effective Dose
C_W Radon Concentration

C_{RW} Consumption Rate of water
D_{CW} Dose Conversion Factor
E_A Radon Exhalation Rate in term of Area
C Integrated Radon Exposure
V Volume of the air in the Cup
λ Decay Constant for Radon-222
C_d dissolved radon concentration

References:

[1] N. M. Ahmed, A. R. Hatif, A. Falih and N. H. binti Kamarudin, "Radon Monitoring by Alpha Track Detection Using Cn-85 Plastic Track" ARID International Journal for Science and Technology (AIJST), 4(8)(2021)131-149

[2] N. F. Tawfik., H.L. Mansour and M.S. Karim, "Measurement of Radon Gas Concentrations in Tap Water for Baghdad Governorate by Using Nuclear Track Detector (CR-39)", International Journal of Physics, 3(6) (2015)233-238

[3] H. I. Asaad, "Measurement of Radon Activity concentration in Iraqi Kurdistan Soil by Using CR-39 Nuclear Track Detectors", M.Sc. Thesis, Univ. of Salahaddin, Erbil-Iraq, (2004).

[4] S. Harb, A. H. El-Kamel, A. M. Zahran, A. Abbady and F.A. Ahmed "Assessment of natural radioactivity in soil and water samples from Aden governorate south of Yemen region" International Journal of recent research in Physics and Chemical Sciences, 1(1)(2014)1-7

[5] L. A. Najam, M.S. Karim and T.K. Hameed., "Measurement of Radon Gas Concentration in Tap Water Samples in Wassit Governorate by Using Nuclear Track Detector (CR-39) ", International Journal of Physics, 4(5) (2016) 119-122

[6] A. R. H. Subber, A.A. Mohammed, and T. M. Al-Asadi, "The Determination of Radon Exhalation Rate from Water using Active and Passive Techniques", Advances in Applied Science Research, 2(6) (2011) 336-346

[7] N.F. Tawfiq, "Uranium and radon concentration in ground water in Aucashat city (Iraq) and the associated health effects, "Advances in Applied Science Research, 4(3) (2013) 167-171

[8] A.J. Khan, A.K. Varshney, R. Prasad, R.K Tyagi and T.V. Ramachandran, "Calibration of a CR-39 plastic track detector for the measurement of radon and its daughters in dwellings"; Nucl Tracks Radiat. Meas., 17 (1990) 497-502

[9] O. Amalds, N.H. Custball and G.A. Nielsen, "Cs137 in Montarq Soils", Health Physics, 57(6) (1989) 955-958

[10] S.A. Durrani and R.K. Bull, "Solid State Nuclear Track Detection: Principles, Methods and Applications", Pergammon Press, U.K, (1987)

[11] M.N. Alam, M.I. Chowdhry, M. Kamal, S. Ghose, M. N Islam and M. Awaruddin, "Radiological Assessment of Tap Water of the Chittagong Region of Bangladesh", Radiat. Prot. Dosim., 82 (1999) 207-214

[12] A.O. Ferreira, B.R. Pecequilo, and R.R. Aquino, "Application of a Sealed Can Technique and CR-39 detectors for measuring radon emanation from undamaged granitic ornamental building materials", Radioprotection Journal, 46 (6) (2011) 49-54

[13] K. Kant, S.B. Upadhyay and S.K. Chakarvarti, "Alpha activity in Indian thermal springs" Iran. J. Radiat. Res., 2 (4) (2005) 197-204

[14] H. Najem, I.J. AL-Khalifa and H.B. Salman, "Determination of radon concentration in soil of Basrah governorate by using solid state nuclear track detectors", Basrah Science Journal, 26(1) (2012) 38-48

[15] EPA, Environmental Protection Agency regulations, Final Rule for Non-Radon Radionuclides in Tap Water, Technical Fact Sheet, EPA, 815-F-00-013, (2000)

[16] K. Ali, "Natural Radioactivity for Different Water Samples in Qena Governorate", M.Sc. Thesis, South Valley University, Egypt, (2014)

[17] O. S. Ajayi and G. Adesida, "Radioactivity in Some Sachet Drinking Water Samples Produced in Nigeria". Iran. J. Radiat. Res., 7(3) (2009) 151-158

[18] C. B. Wiseman, "Determination of the Activity Concentrations of Radon-222 and Radon-220 in Water and Soil Samples from Newmont-Akyem Gold Mine Using Gamma Spectrometry", Thesis MPhil, Nuclear Science and Technology Degree, University of Ghana, Legon, (2015)

[19] S.Yan**,** G. Wa, S. Tuya, L. Zhigang, Z. Jianwei, G. Rongshu, L Jinfeng., S. Peilin and Z. Hongtao, "The gross α and β radioactivity levels of drinking water source in one oil industrial city in northeast China", Radiation Medicine and Protection, 2 (2021) 61–66

[20] L. V. Giuseppe, A. Valeria, D'A. Vittoria, L. Marco, M. Commara, S.P. Panico, and P. Mariagabriella, "Measurement of Natural Radionuclides in Drinking Water and Risk Assessment in a Volcanic Region of Italy, Campania", Water, 13 (2021) 11-15

[21] A.I. Alabdula'aly, "Occurrence of radon in groundwater of Saudi Arabia", Journal of Environmental Radioactivity, 138 (2014)186–191

[22] W.R. Alharbi, G.E. Adel, A. Abbady, A. Al-Taher, "Radon Concentrations Measurement for groundwater Using Active Detecting Method", American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS), 14 (1) (2015) 1-11

[23] W.A. Abdurabu, A.T. Ramli, M.A. Saleh and A. Heryansyah, "The activity concentrations of ^{222}Rn and Corresponding Health Risk in Groundwater Samples from Basement and Sandstone Aquifer; the Correlation to Physicochemical Parameters", Radiation Physics and Chemistry, 127 (2016) 34–41

[24] K. Noah, D. Asare, A. P. Partick, A. Eric and D.W. David, "Measurement of Radon Concentration in Groundwater in the Ashanti Region of Ghana", Journal of Radioanalytical and Nuclear Chemistry, 317 (2018) 675–683

[25] T. Wanyu, L. Yonngme, T. Kaixuan, X. Yanshi, H. Shili and W. Peng, "Distribution of Radon and Risk Assessment of its Radiation Dose in Groundwater Drinking for Village People Nearby the W-Polymetallic Metallogenic District at Dongpo in Southern Hunan Province, China", Applied Radiation and Isotopes, 151 (2019) 39–45

[26] A.S. Alaboodi, N.A. Kadhim, A.A. Abojassim, A. B. Hassan, "Radiological Hazards due to Natural Radioactivity and Radon Concentrations in Water Samples at Al-Hurrah City, Iraq", International Journal of Radiation Research, 18(1) (2020) 1-11

[27] HK Shu'aibu, MU Khandaker., A. Baballe, T. Salisu and A. A. Mohammed, "Determination of Radon Concentration in Groundwater of Gadau, Bauchi State, Nigeria and Estimation of Effective Dose". Radiation Physics and Chemistry, 178 (2021) 108934

[28] A. Kumar, M. Kaur, S. Sharma, and R. Mehra, "A study of Radon Concentration in Drinking Water Samples of Amritsar City of Punjab (India)", Radiation Protection and Environment, 39 (1) ,(2016) 13-19