ISSN: 2476-2377

Research Article

International Journal of Cancer Research & Therapy

Rn-222 Activity Concentration and Age-Dependent Annual Effective Dose Analysis of Drinking Water Sources in Southern Benue State, Nigeria.

Andrew Ichoja[1*], O.O. Agboola[2], E. Danladi[1], S. Hashim[3], N. Habila[4] and E. O. Adejo[1]

[1]*Department of Medical Physics, Faculty of Science, Federal University of Health Sciences, Otukpo, Benue State, Nigeria*

[2]*Department of Biological Sciences, Faculty of Science, Federal University of Health Sciences, Otukpo, Benue State, Nigeria*

[3]*Department of Physics, Faculty of Science, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia*

[4]*Department of Science, School of Science and Technology, Plateau State Polytechnic, Bukuru, Jos, Plateau State, Nigeria*

[*]Corresponding Author
Andrew Ichoja, Department of Medical Physics, Faculty of Science, Federal University of Health Sciences, Otukpo, Benue State, Nigeria.

Submitted:2023, Nov 30 ; **Accepted**: 2023, Dec 27; **Published**: 2023, Dec 30

Citation: Ichoja, A., Agboola, O.O., Danladi, E., Hashim, S., Habila, N., et al. (2023). Rn-222 Activity Concentration and Age-Dependent Annual Effective Dose Analysis of Drinking Water Sources in Southern Benue State, Nigeria. *Int J Cancer Res Ther, 8*(4), 209-222.

Abstract

Radon is one of the carcinogenic radioactive gases causing radiological risk to the public via ingestion and inhalation. The 222Rn activity concentrations were estimated in potable water of Benue South (Otukpo and Ado Local Government Areas) using the Tri-Carb 1000 Liquid Scintillation Counter (LSC). 222Rn activity for Ado and Otukpo LGAS ranged from 2.281±1.861 to 27.525±1.861 Bq/L with a mean value of 10.031±1.861 Bq/L and 2.115±0.689 to 11.367±0.689 Bq/L with an arithmetic mean of 7.574±0.689 Bq/L respectively. The radon levels are within the reference level of 100 Bql−1 proposed by the WHO and EU Commission. Nearly 33% of the potable water had radon activity levels exceeding the maximum contamination level of 11.1 Bql−1 proposed by USEPA. The annual average ingestion dose values are lower than the action level of 100 µSvy−1 as proposed by the WHO and EU Commission. The values of dose variations of Annual effective dose (AED) to individuals were found to increase with age and water consumption rates. The estimated mean radio sensitivity for the different age groups followed a decreasing trend of Adults>Children>Infants in both Ado and Otukpo LGAs. The radiation dose for inhalation received by individual lungs from consumption of radon in water samples from Ado and Otukpo LGAs was significantly higher than the corresponding radiations received by the walls of the stomach. In conclusion, there is a possible occurrence of cancerous bronchial epithelium than stomach cancer over time in the study areas due to the consumption of water.

Keywords: Radioactivity, Ingestion, Radiological Risks, Annual Effective Doses, Inhalation

1. Introduction

The critical role of water in human existence cannot be overemphasized. Its usage varies from agriculture, transportation, power generation and domestic consumption, etc. As much as possible, all water sources for consumption and other domestic uses should be without any form of contamination from either microbial, chemical, or radiological sources [1,2]. Water contamination can come in the form of (i) human activities (waste and sewage disposal) (ii) industrialization and (iii) naturally occurring radioactive materials (NORMs) which can adversely affect the quality of drinking water. Exposure to environmental radiation from naturally occurring radioactive elements such as uranium (U-238) and its decay series radium (Ra-226), thoron (Th-220) and radon (Rn-222) pose great health risks to the general population [3]. For instance, Radon, is a member of the spontaneous disintegration of the uranium decay. Both radon and its progenies has been regarded as a potential health hazard in the modern generation [4,5]. This colorless and odorless inert gas, with a density of 9.7 g/l has 3.8 days of half-life and is highly soluble in water. These characteristics are considered to be responsible for the hazardous and toxic nature of Rn-222 gas in underground water. It has been established that Rn-222 contributes more than 50% (1.3 mSv) of the total 2.4 mSv of the general radiological contamination in drinking water [6]. According to United State Environmental Protection Agency (USEPA), prolonged exposure to alpha emission from radon and its polonium (Po-214 and Po-218) progenies has been categorized as a potential cause of lung cancer and the leading contributor to the annual effective dose received by humans [7]. The World Health Organization (WHO) on the other hand has classified Radon-222 as a lung cancer carcinogen and a leading cause of lung cancer for non-smokers and the second contributing factor for lung cancer among smokers after smoking [8]. Injection or inhalation of air from radon-enriched substances is the two known pathways of radon entrance into humans with its attending consequences on the internal organs [4]. Diseases such as liver disease, anemia, cataracts, bone growth, gastro internal and stomach cancer, kidney disease, etc are attributable to ingestion or inhalation of Rn-222 over time [9,10]. Rocks and soils have been identified as the main entry routes of radon in water sources. As such, areas that are rich in uranium contents are likely to have high radon deposits due to the leaching of soils and rocks into underground water sources such as wells and boreholes [11].

The following authors have investigated and reported the presence of high activity concentration of radon in public drinking water globally and low levels of radon activities in water source [12-18]. Locally, Garba et al. (2013), assessed the radon concentration in drinking water samples from Zaria and its environment and discovered that the Rn□222 concentration for both boreholes and open wells was as well above the maximum contamination level of 11.1 Bq/L prescribed by USEPA. In Ado□Ekiti, Nigeria, Oni et al. (2016) measured the radon concentration in drinking water using calibrated active electronic detector RAD7. The investigated 64 water samples collected from various locations of Ado-Ekiti revealed that 53% of the studied water samples have Rn-222 concentration above the 11.1 Bq/L safe limit. Kumar et al. (2016), investigated the annual effective dose due to inhalation and injection of radon in water samples from some selected Indian regions. Their assessment revealed that the total annual effective dose of 10 to 177μSv/y was found in the acceptable region set by the global health agency. Other authors recorded various forms of annual effective dose in the following categories: 2.77−33.39 μSv/y, $2.258 \times 10^{-5} - 1.458 \times 10^{-4}$ μSv/y and 0.036−12.61 mSv/y [17,19,20].

For the safety of the general population and to avert the consequence of the associated health risks due to overexposure to environmental radiation, it is, therefore, necessary to appraise the level of Rn-222 in underground drinking water sources in the study areas. To the best of our knowledge, there is no sufficient study on the natural radionuclides of underground drinking water samples in the study areas. Hence, the current work is aimed at determine the concentration of radon activity and to assess the corresponding radiological risks of different age groups that depend on the underground drinking sources. For this reason, the present work was carried out in the dry season between January and March 2023, when dwellers rely heavily on underground water sources for survival due to acute water shortages in these periods.

2. Materials and Method

2.1. Description of Study Area

Benue State is situated between Latitudes 6o 30'N and 8o 15'N and Longitudes 7o 30'E and 10o 00'E with a land area of about 34,059 km2 and a population of 2,780,398 by 1991 Census and 4,253,541 by 2006 estimate. The study area covers 12 out of the 23 Local Government Areas (LGAs) of Benue State, namely: Ado, Obi, Oju, Konshisha, Gboko, Ushongo, Vandeikya, Tarka, Buruku, Logo, Katsina-Ala and Ukum. Benue State experiences two distinct seasons, the wet season and the dry season. The rainy season lasts from April to October with annual rainfall in the range of 1120 to 1500 mm. The dry season begins in November and ends in March. The climate is characterized by a high-temperature regime, ranging from 27-38 0C as the mean annual. The relative humidity is between 60 and 80%. It has a vegetation cover of the guinea savannah type. The main river systems include the River Benue and the River Katsina-Ala which together with their tributaries, traverse the area. The drainage system of the Cross River basin bordering the lower Benue basin to the south rises from the area, through the River Konshisha and its tributary rivulets and streams, flowing southwards into the main basin of the Cross River to the south. The region is well-drained and presents good potential for water resource development. The stream flow over the impermeable geological environments indicates low groundwater components and very high runoff.

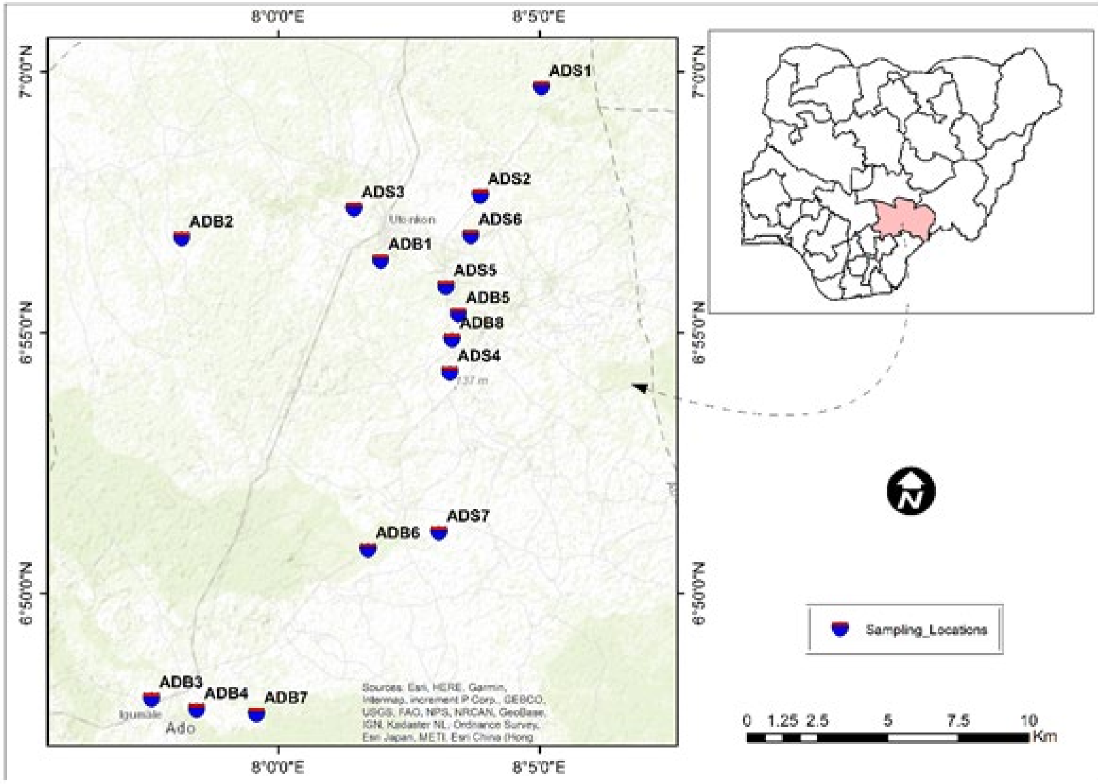

Figure 1: Study Area Map for Ado Local Government Area

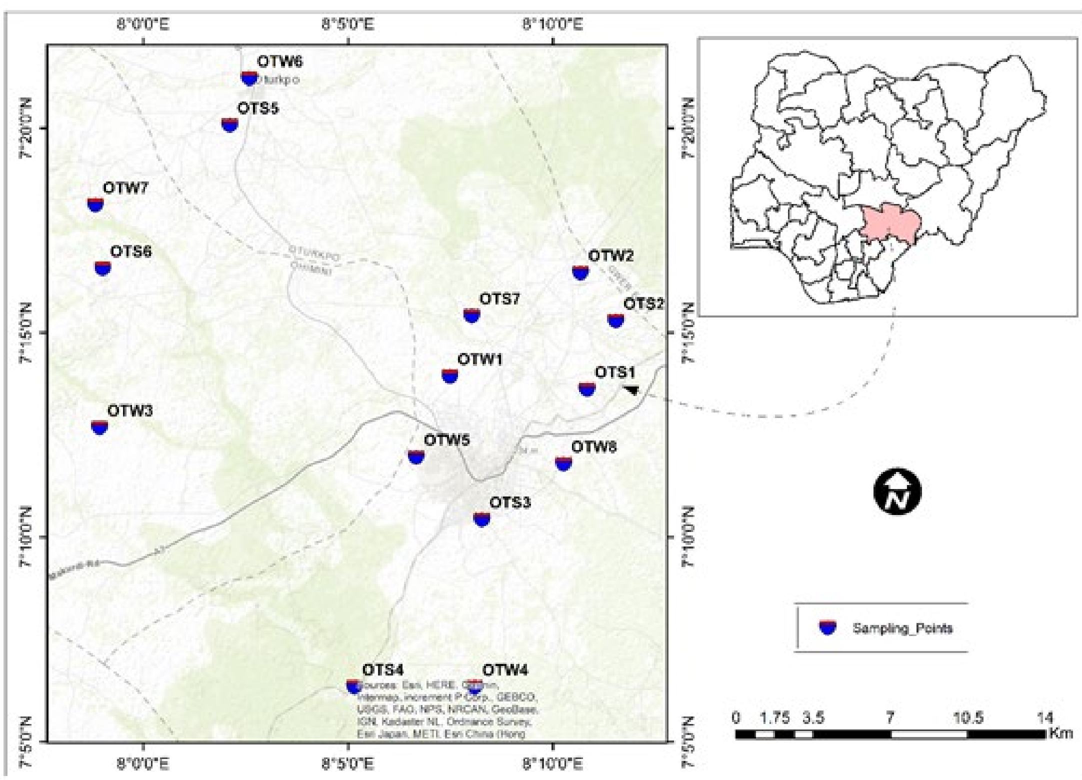

Figure 2: Study Area Map for Otukpo Local Government Area

2.2. Materials

2.2.1. Sample Collection

In the present work, a stratified random sampling technique is used. Fifteen (15) water samples (wells, boreholes, or steam) were collected at different locations from Ado and Otukpo Local Government Areas of Benue State, Nigeria. At each location, a global positioning system (GPS) was used to mark the exact geographical locations and mapping of the sample collection point as shown in figures 1 and 2. A total of thirty (30) water samples in all were collected from various water sources and analysed. 100 ml plastic vials used for the collection of water samples were initially washed and rinsed with distilled water to reduce radon contamination. For the borehole water sample, the borehole was pumped for at least three (3) minutes to ensure only fresh water was collected for the analysis. Each water sample collected was labelled appropriately with indelible ink, and both the time and date of the collection were noted and recorded. During water collection from the well, the sample source was purged several times with the aid of a bailer and allowed to refill to enhance the quality of the collected samples before they were quickly transferred into the pre-cleansed plastic vials. For the collection of surface water (stream), the plastic vials were completely submerged in water to a depth of 20 -30 cm and until filled and tightly capped before being taken out of the water to avoid outgassing of the dissolved radon gas from water samples.

3. Sample Preparation

With the aid of a hypodermic syringe and needle, 20 ml scintillation vials containing a toluene scintillation cocktail were filled with 10 ml of each of the water samples. Following the application of the standard sampling technique, the scintillation vials were capped firmly to minimize outgassing and energetically shaken for several minutes. The presence of toluene is to prevent possible loss of Rn-222 gas during transportation and storage due to leakages and for quick extraction of Rn-222 gas into the organic scintillator. Similarly, a blank vial for background radiation measurement was prepared with the previously preserved and kept distilled water. Thereafter, the prepared samples were left for a minimum of three (3) minutes undisturbed for the Rn-222 decay product and its progenies to attain equilibrium before counting. The actual Rn-222 gas measurement was done for 60 minutes using a liquid scintillation counting analyser with energy discrimination for alpha particles.

3.1. Sample Analysis

The prepared samples and the blank for background measurement were analysed using Liquid Scintillation Counter with model identity (Packard Tri-Carb LSA 1000TR) located at the Centre for Energy Research and Training (CERT), Ahmadu Bello University Zaria, Kaduna State. In Liquid Scintillation Analysis, the samples emit radiation and the energy from the emitted radiation is transported to the organic scintillator (fluorescent material) and re-emitted in the form of a light photon. The photomultiplier component of the scintillator detects the light photon and converts it into electrical energy for counting. This way each emission result is a pulse of light in the form of a digit.

The Liquid Scintillation Counter was calibrated using radium (Ra-226) standard solution from International Atomic Energy Agency (IAEA). The calibration process was completed before the analysis. In the present work, both Ra-226 standard samples and the background count were counted for the same period of 60 minutes in compliance with standard procedure.

In the current research, the time elapsed for sample collection and analysis were corrected using equations 1. Whereas, the annual effective dose for Ingestion and Inhalation were estimated from the measured sample and background radiation using the equations 3 and 4 respectively as described in [17].

$$A_t(BqL^{-1}) = A_0 exp^{-\lambda t} \qquad (1).$$

where:
A_t = Measured concentration at time (t); A_0 = Initial concentration to be calculated after decay correction, λ = Decay constant, t = Time elapsed since sample collection
But

$$\lambda = \frac{ln2}{t_{1/2}} = \frac{0.963}{3.8} = 0.182 \qquad (2)$$

$$AED_{inh}(mSv/y) = C_{Rn} \times R_{wa} \times D \times F_w \times I_{avg} \qquad (3)$$

where:
AED_{inh} = Annual effective dose due to inhalation; C_{Rn} = Radon concentration; R_{wa} = Ratio of radon in water to radon in air (10^{-4}); D = Dose conversion factor (9 x 10^{-6} mSv/Bq); F_w = Equilibrium factor (0.4); I_{avg} = Average indoor occupancy (7000 hy^{-1})

$$AED_{ing} = C_{Rn} \times C_w \times D_{CF} \qquad (4)$$

where:
AED_{ing} = Annual effective dose for radon ingestion, C_{Rn} = Radon concentration in water
C_w = Annual water consumption by an individual per day per litre (730 L/Y, 365 L/Y and 200 L/Y) for adults, children and infants respectively, D_{CF} = Dose conversion factor (3.5×10^{-9} $SvBq^{-1}$) [21,22]. The radiation doses to the stomach and lungs (internal organs) were estimated by multiplying the annual effective doses for ingestion and inhalation by the respective tissue weighting factors for the stomach and lungs. Standard error (SE) associated with the samples was calculated using equation 5 to measure the accuracy with which the sample represents the population

$$SE = \frac{\sigma}{\sqrt{n}} \qquad (5)$$

where σ is the sample standard deviation and n is the total number of samples

4. Result and Discussion

Tables 1 and 2 summarized the specific activity concentration of radon in water samples, radiation dose due to ingestion for different age groups (Adults, age > 17years; Children, 12 – 15 years and Infants, age < 2 years) and inhalation of the air emanating from water samples to internal organs (stomach and lungs) for Ado and Otukpo LGAs. From the tables, it can be observed that the arithmetic mean values of Rn-222 concentration for the studied water samples were found to be 10.031±1.861 and 7.575±0.689 Bq/L for Ado and Otukpo LGAs respectively. The annual effective dose for radon intake in water (ingestion) for three (3) categories of people in the two (2) LGAs have been analysed. For Ado LGA, the annual effective dose was found to be 25.629±4.753, 12.815±2.377 and 7.022±1.303 μSv/y for adults, children, and infants respectively. Meanwhile, the corresponding dose equivalent due to intake of Rn-222 from water samples in Otukpo LGA was found to be 19.353±1.759, 9.677±0.0850 and 5.302±0.482 μSv/y respectively for the same set of people. For radiation dose received by internal organs, the average values of absorbed dose by stomach and lungs for Ado LGA were 294.738±54.677 and 303.339±56.273 μS/v respectively, while the corresponding values to internal organs for Otukpo LGA were found to be 222.561±20.232 and 229.056±20.822 μS/v respectively.

The analysis showed that all (100%) the mean values of Rn-222 concentration evaluated for both LGAs were found within the permissible region (4-40 Bq/l) proposed by World Health Organization (WHO). Again, the dose equivalent received by individuals from the LGAs under study was significantly below the global mean values of 1.0 and 0.1 mSv/y recommended by WHO and UNSCEAR respectively. However, the radiation dose for inhalation received by internal organs showed that the dose to the lungs is higher compared to the equivalent dose to the stomach. All the average values due to inhalation for internal organs were below 0.1 mSv/y prescribed by European Union Commission.

4.1. Evaluation of Surface Water (stream) Samples

The Rn-222 activity concentrations for Ado and Otukpo LGA were calculated using Equation 1. The radon concentration were ranged from 2.281±1.499 Bq/L to 13.229±1.499 Bq/L with mean value of 6.777±1.499 Bq/L and 2.115±1.067 Bq/L to 10.395±1.067 Bq/L with an average value of 6.614±1.067 Bq/L respectively. The highest values of Rn-222 (13.229±1.499 and 10.395±1.067 Bq/L) were recorded at ADS2 (Apa-Agila) and OTS5 (Ogobia) respectively while locations like ADS5 (Ayaga) and OTS6 (Ogoli) as shown in Figures 3 and 4 recorded the lowest values of radon concentration. The mean value of annual effective dose for ingestion of Rn-222 in water samples from Ado and Oukpo LGAs were (17.315±3.830, 8.658±1.915 and 4.744±1.049 µSv/y) and (4.630±0.747, 194.335±31.340 and 200.007±32.255 µSv/y) respectively for Adults, children and infants. Meanwhile, the average values of radiation dose to stomach and lungs from water samples in Ado LGA were 199.124±44.050 and 204.94±45.366 µSv/y while the equivalent mean dose to stomach and lungs for Otukpo water samples were 194.335±31.340 and 200.007±32.255 µSv/y respectively.

Sample ID	Latitude (°N)	Longitude (°E)	Rn-222 (Bq/L)	AED Due to Ingestion (µSv/y)			AED to Internal Organs (µSv/y)	
				Adults	Children	Infants	Stomach	Lungs
ADS1	$6^{\circ}59'41.2''$	$8^{\circ}5'2.4''$	9.950±1.86	25.423±4.76	12.712±2.38	6.965±1.30	292.367±54.68	300.899±56.27
ADS2	$6^{\circ}57'36.9''$	$8^{\circ}3'51.9''$	13.229±1.86	33.801±4.76	16.900±2.38	9.260±1.30	388.706±54.68	400.05±56.27
ADS3	$6^{\circ}56'50.2''$	$8^{\circ}3'2.5''$	3.295±1.86	8.420±4.76	4.210±2.38	2.307±1.30	96.829±54.68	99.655±56.27
ADS4	$6^{\circ}54'51.5''$	$8^{\circ}3'18.7''$	3.726±1.86	9.520±4.76	4.760±2.38	2.608±1.30	109.483±54.68	112.678±56.27
ADS5	$6^{\circ}55'51.7''$	$8^{\circ}3'12.7''$	2.281±1.86	5.829±4.76	2.914±2.38	1.597±1.30	67.028±54.68	68.985±56.27
ADS6	$6^{\circ}56'50.2''$	$8^{\circ}3'2.5''$	7.672±1.86	19.602±4.76	9.801±2.38	5.370±1.30	225.419±54.68	231.998±56.27
ADS7	$6^{\circ}51'9.2''$	$8^{\circ}3'4.6''$	7.285±1.86	18.612±4.76	9.306±2.38	5.099±1.30	214.037±54.68	220.284±56.27
ADB1	$6^{\circ}56'50.5''$	$8^{\circ}3'2.4''$	15.383±1.86	39.303±4.76	19.651±2.38	10.768±1.30	451.982±54.68	465.173±56.27
ADB2	$6^{\circ}56'47.8''$	$7^{\circ}58'9.1''$	27.525±1.86	70.327±4.76	35.164±2.38	19.268±1.30	808.766±54.68	832.369±56.27
ADB3	$6^{\circ}47'46.8''$	$7^{\circ}58'9.8''$	13.979±1.86	35.717±4.76	17.859±2.38	9.786±1.30	410.75±54.68	422.737±56.27
ADB4	$6^{\circ}47'57.5''$	$7^{\circ}58'39.9''$	3.657±1.86	9.342±4.76	4.671±2.38	2.560±1.30	107.442±54.68	110.578±56.27
ADB5	$6^{\circ}54'51.5''$	$8^{\circ}3'19.9''$	5.407±1.86	13.816±4.76	6.908±2.38	3.785±1.30	158.878±54.68	163.515±56.27
ADB6	$6^{\circ}50'49.6'$	$8^{\circ}1'43.1''$	5.115± 1.86	13.070±4.76	6.535±2.38	3.581±1.30	150.306±54.68	154.692±56.27
ADB7	$6^{\circ}48'3.3''$	$7^{\circ}58'43.2''$	10.909±1.86	27.873±4.76	13.936±2.38	7.636±1.30	320.534±54.68	329.888±56.27
ADB8	$6^{\circ}54'51.2'$	$8^{\circ}3'19.7''$	21.051±1.86	53.786±4.76	26.893±2.38	14.736±1.30	618.536±54.68	636.588±56.27
Minimum			2.281±1.86	5.829±4.76	2.914±2.38	1.597±1.30	67.028±54.68	68.985±56.27
Maximum			27.525±1.86	70.328±4.76	35.164±2.38	19.268±1.30	808.766±54.68	832.369±56.27
Mean			10.031±1.86	25.629±4.76	12.815±2.38	7.022±1.30	294.738±54.68	303.339±56.27

Table 1: Activity Concentration (Bq/L) and Annual Effective Doses (AED) for Ingestion and Inhalation (µSv/y) for Ado LGAs

Sample ID	Latitude (°N)	Longitude (°E)	Rn-222 (Bq/L)	AED Due to Ingestion (µSv/y)			AED to Internal Organs (µSv/y)	
				Adults	Children	Infants	Stomach	Lungs
OTS1	7.2226°	8.1456°	6.963±0.69	17.791±1.760	8.896±0.88	4.874±0.48	204.6±20.23	210.571±20.82
OTS2	7.2484°	8.1589°	9.200±0.69	23.506±1.760	11.753±0.88	6.440±0.48	270.323±20.23	278.212±20.82
OTS3	7.1737°	8.1378°	5.213±0.69	13.319±1.760	6.659±0.88	3.649±0.48	153.164±20.23	157.634±20.82
OTS4	7.1056°	8.086°	7.644±0.69	19.531±1.760	9.765±0.88	5.351±0.48	224.601±20.23	231.156±20.82
OTS5	7.3541°	8.0426°	10.395±0.69	26.559±1.760	13.280±0.88	7.276±0.48	305.429±20.23	314.343±20.82
OTS6	7.3607°	7.8932°	2.115±0.69	5.403±1.760	2.701±0.88	1.480±0.48	62.130±20.23	63.943±20.82
OTS7	7.2536°	8.1581°	4.768±0.69	12.183±1.760	6.091±0.88	3.338±0.48	140.009±20.23	144.188±20.82
OTW1	7.2226°	8.1455°	9.659±0.69	24.678±1.760	12.339±0.88	6.761±0.48	283.794±20.23	292.076±20.82
OTW2	7.2547°	8.1753°	7.019±0.69	17.933±1.760	8.967±0.88	4.913±0.48	206.231±20.23	212.25±20.82
OTW3	7.2296°	7.1669°	11.367±0.69	29.044±1.760	14.522±0.88	7.957±0.48	334.005±20.23	343.753±20.82
OTW4	7.1071°	8.0967°	3.976±0.69	10.159±1.760	5.080±0.88	2.783±0.48	116.831±20.23	120.24±20.82
OTW5	7.2119°	8.1201°	9.547±0.69	24.394±1.760	12.197±0.88	6.683±0.48	280.529±20.23	288.716±20.82
OTW6	7.3535°	8.0432°	10.0750.69	25.743±1.760	12.871±0.88	7.053±0.48	296.041±20.23	304.68±20.82
OTW7	7.3644°	7.8934°	6.602±0.69	16.868±1.760	8.434±0.88	4.621±0.48	193.984±20.23	199.646±20.82
OTW8	7.2092°	8.1493°	9.075±0.69	23.187±1.760	11.593±0.88	6.353±0.48	266.649±20.23	274.431±20.82
Minimum			2.115±0.69	5.403±1.760	2.701±0.88	1.480±0.48	62.130±20.23	639.429±20.82
Maximum			11.367±0.69	29.044±1.760	14.522±0.88	7.957±0.48	334.005±20.23	343.753±20.82
Mean			7.575±0.69	19.353±1.760	9.677±0.88	5.302±0.48	222.561±20.23	229.056±20.82

Table 2: Activity Concentration (Bq/L) and Annual Effective Doses (AED) for Ingestion and Inhalation (µSv/y) for Otukpo LGAs

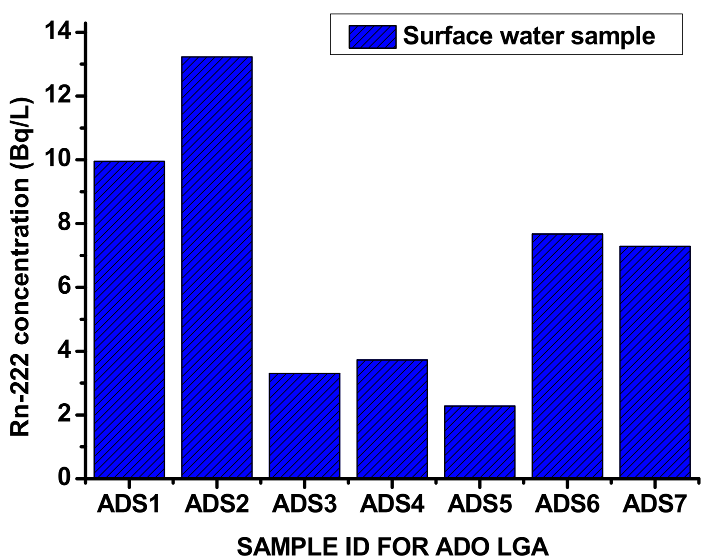

Figure 3: Distribution of Rn-222 concentration in surface water samples from Ado LGA

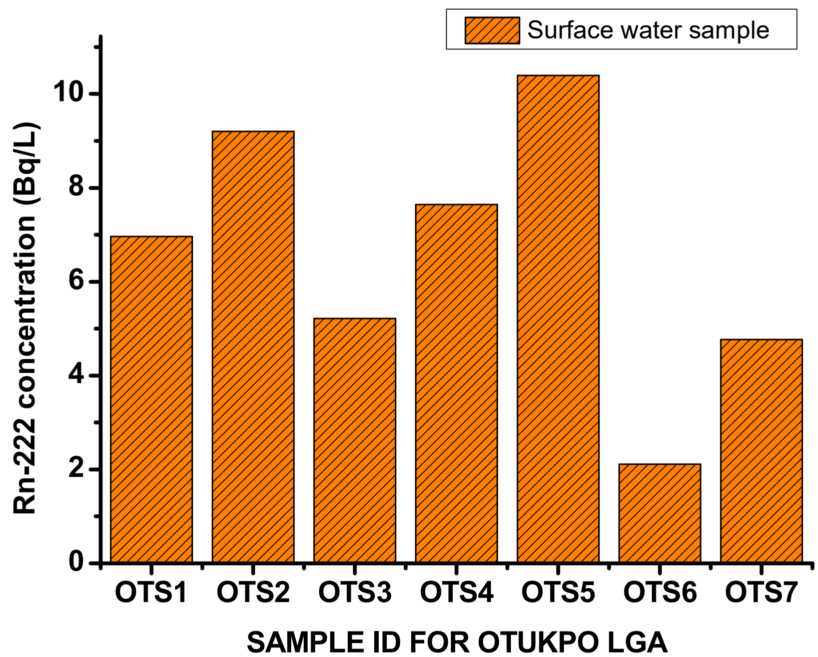

Figure 4: Distribution of Rn-222 concentration in surface water samples from Otukpo LGA

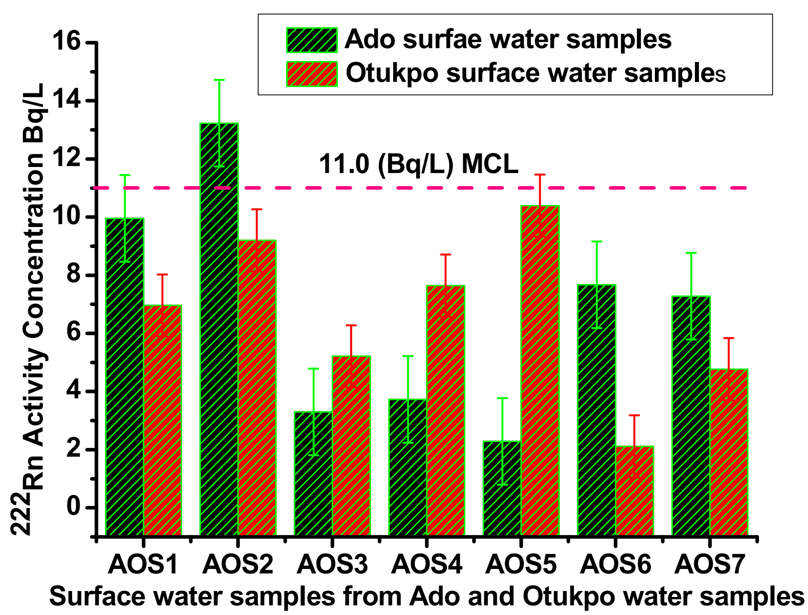

Figure 5: Comparison of Rn-222 in surface water samples from Ado and Otukpo

Approximately 86% of all the activity concentration of surface water samples from Ado LGA fell within the tolerance level of 4-40 Bq/L recommended by the United Nations Scientific Committee on the Effect of Atomic Radiation, while 14% of the evaluated samples exceeded the maximum contamination level of 11 Bq/L suggested by United State Environmental Protection Agency [7,21]. The observed higher value of Rn-222 concentration could be attributed to the geology of the environment, geochemical characteristics, radionuclides presence and uranium content of the bedrock [23,24]. The analyzed surface water samples from Otukpo LGA revealed that 100% of Rn-222 concentration is below the baseline of 100 Bq/L and 11 Bq/L recommended by the World Health Organization (WHO) and USEPA respectively. Therefore, the surface water sources with Rn-222 values below the set marks could be used for domestic applications without any immediate radiological health risks. The obtained Rn-222 results from both LGAs are lower than those reported by higher than the recorded values in and significantly consistent with the works carried out by [17-19,24,25].

International health regulatory agencies like World Health Organization and European Union Commission have set 0.1 mSv/y as the maximum annual effective dose contribution in drinking water from radioisotopes such as Rn-222, K-40 and H-3, while UNSCEAR (2000) proposed the value of 1 mSv/y as an annual effective dose limit for members of the public [5]. In the present study, the annual effective dose from surface water consumption in Ado LGA ranged from 5.829±3.830 to 33.801±3.830 μSv/y for adults, 2.914±1.915 to 16.900±1.915 μSv/y for children and 1.597±1.049 to 9.260±1.049 μSv/y for infants, while the corresponding dose to individuals in Otukpo LGA from drinking surface water was found in the region of 5.403±2.725to 26.559±2.725 μSv/y for adults, 2.701±1.363 to 13.280±1.363 μSv/y for children and 1.480±0.747 to 7.276±0.747 μSv/y for infants respectively. The annual effective doses from both LGAs were found to increase with the age of the individual consumer and water consumption rates. Despite the radio sensitivity of infants and contrary to the work carried out by SILAS (2017), the dose rates to adults were found to be higher compared to the dose received by infants due to individual water consumption variation. Similarly, the radiation dose to the stomach and lungs from the two (2) LGAs varied from 67.028±44.050 to 388.706±44.050 μSv/y, 68.984±45.366 to 400.05±45.366 μSv/y and 62.130±31.340 to 305.429±31.340 μSv/y, 63.942±32.255 to 314.343±32.255 μSv/y respectively. Comparing the results of activity concentration from Ado and Otukpo LGAs as represented in Figure 5, the results showed that the evaluated surface water sources from Ado LGA have more radon concentration than those from Otukpo LGA and therefore could pose higher health risks to consumers.

The statistical values from the samples being studied as represented in Figure 6, revealed that the contribution of radiation dose to lungs from surface and borehole water samples in Ado LGA is greater than those impacted from Otukpo surface water. This implies that there might be high potential gastrointestinal cancer risks in Ado compared to possible stomach cancer from the consumption of water samples from Otukpo LGA [26,27].

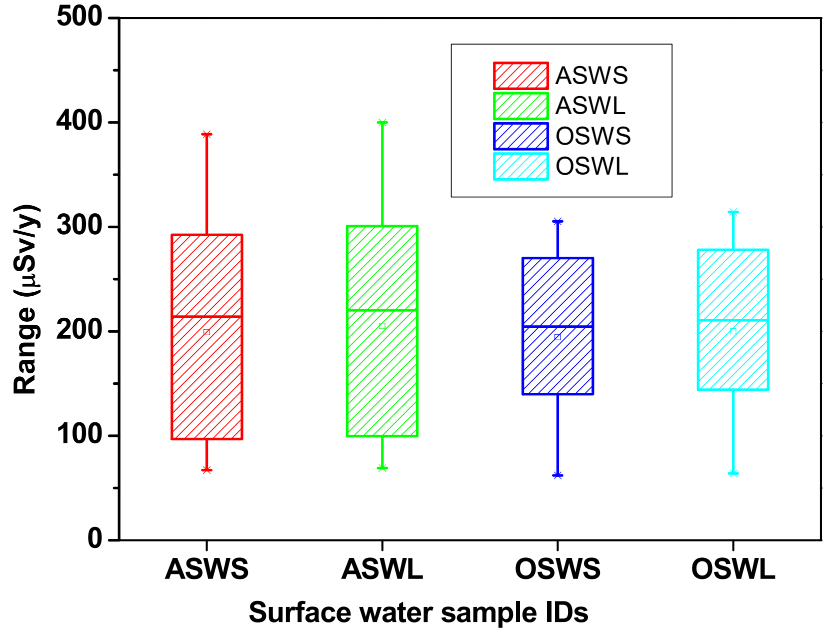

Figure 6: Statistical values of radiation doses for ingestion and inhalation from surface water samples

4.2. Evaluation of Underground Water Samples

Figures 7 and 8 illustrate the distribution of radon concentration in the borehole and well water sources from Ado and Otukpo LGAs respectively. The range of activity concentration from the study areas varied from 3.657±2.970 to 27.525±2.970 µSv/y with and an average value of 12.878±2.970 µSv/y and 3.976±0.842 to 11.367±0.842 µSv/y with a mean value of 8.415±0.842 µSv/y respectively. About 50% and 13% of radon concentration in the borehole and well water sources used for domestic and other purposes from Ado and Otukpo LGAs respectively exceeded the reference maximum contamination level (MCL) of 11 Bq/L recommended by [7]. In all, five samples showed values very close to the MCL value but in general, the radon concentration values from the two LGAs were below WHO recommended value of 100 Bq/L [28]. The obtained mean values in the current work are higher than those reported elsewhere [29,30]. The annual effective (AED) dose for various age groups that used the same source of water for drinking is presented in Tables 1 and 2. The AED for borehole water samples in Ado LGA ranges from 9.343±7.587 to 70.328±7.587 µSv/y with a mean value of 32.904±7.587 µSv/y, 4.671±3.794 to 35.164±3.794 µSv/y with an average value of 16.452±3.794 µSv/y and. 2.560±2.079 to 19.268±2.079 µSv/y with an average value of 9.015±2.079 µSv/y for adults, children and infants respectively. The comparative results from the studied regions represented in Figure 9 indicate the presence of a higher concentration of Rn-222 in about 63% of the water samples under investigation from Ado LGA while 37% of Otukpo studied water samples showed greater values of Rn-222 in certain locations.

Furthermore, the annual effective dose to individuals that consumed well water samples in Otukpo LGA varies from 10.159±2.151 to 29.044±2.151 µSv/y with an average value of 21.501±2.151 µSv/y, 5.080±1.075 to 14.522±1.075 µSv/y with a mean value of 10.750±1.075 µSv/y and 2.783±0.589 to 7.957±0.589 µSv/y with an average value of 5.891±0.589 µSv/y for adults, children and infants respectively. These results showed that the total AED received by individuals for consuming borehole and well water sources in Ado and Otukpo LGAs respectively were well below the proposed 1 mSv/y by UNSCEAR and WHO for the public.

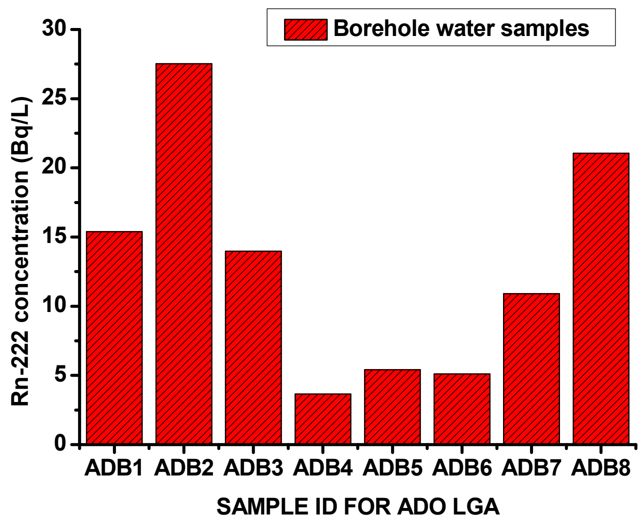

Figure 7: Distribution of Rn-222 concentration in borehole water samples from Ado LGA

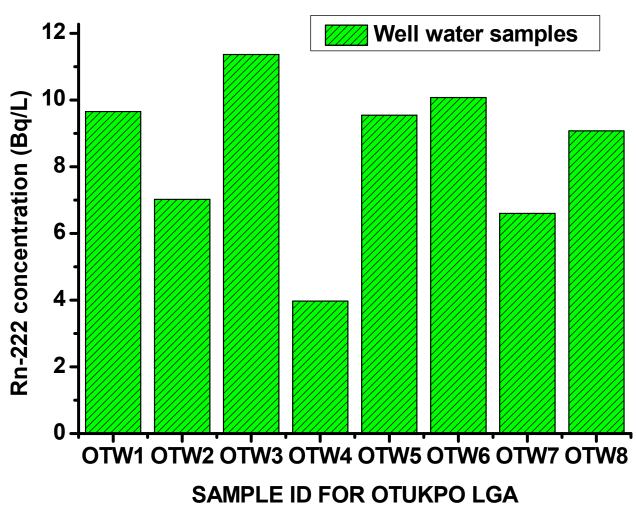

Figure 8: Distribution of Rn-222 concentration in well water samples from Otukpo LGA

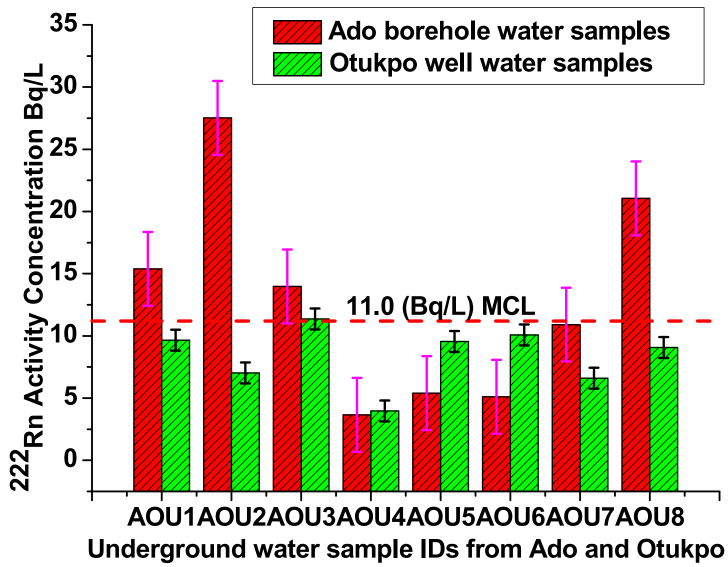

Figure 9: Comparison of Rn-222 in underground water samples from Ado and Otukpo

The results also showed that AED to individuals in both study areas increases with water consumption rates and age (AED received by adults > AED to children > AED to infants). The achieved results in the present work are closely related to works reported by Ravikumar & Somashekar, (2018) but contrary to Chen (2010) [24,31].

The annual radiation dose to the stomach due to ingestion of radon in drinking boreholes and well water sources in Ado and Otukpo LGAs varies considerably from 107.442±87.252 to 808.766±87.252 with a mean value of 378.399±87.252 and 116.831±24.733 to 334.005±24.733 with an average value of 247.258±24.733 respectively. On the other hand, the radiation doses to lungs due to inhalation of radon in the borehole and well water sources from Ado and Otukpo LGAs ranged from 110.58±89.799 to 832.37±89.799 µSv/y with a mean value of 389.44±89.799 µSv/y and 120.24±25.45 to 437.53±25.45 µSv/y with an average value of 254.474±25.454 µSv/y respectively. It is evident from the results as illustrated in Figure 10 that the values of radiation dose to lungs for consumption of borehole water samples by individuals in Ado LGA are significantly higher compared to the dose received by individuals that used well water samples for domestic applications in Otukpo LGA. The higher values of radiation dose in borehole water samples might be associated with the depth of the borehole which reduced the aeration of radon gas due to outgassing and fast dissolution of radon in water under pressure leading to high accumulation of radon in underground water sources [32,33]. The higher values of radiation dose to lungs from studied samples in Ado relative to low dose

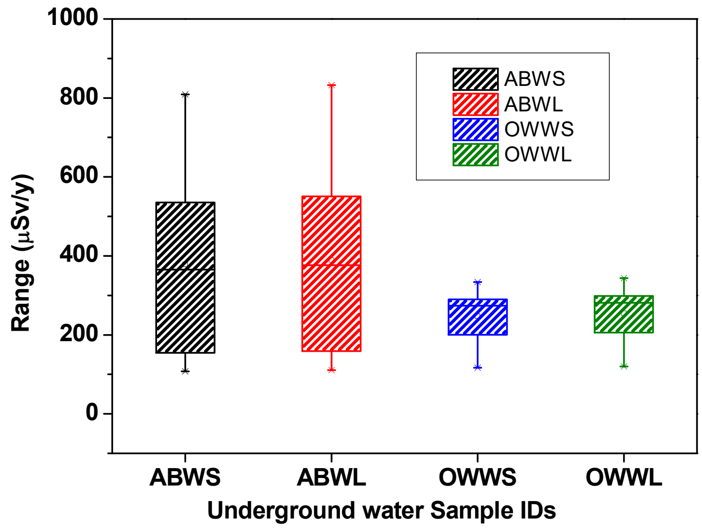

Figure 10: Statistical values of radiation doses for ingestion and inhalation from groundwater samples

5. Conclusion

It can be concluded from the current study that the values of activity concentration of Rn-222 in the majority of the studied surface and underground water samples were well lower than the proposed safe values by WHO and UNSCEAR. Few water samples from the borehole and well in the study areas contained higher values of radon concentration than the allowable contamination level of 11 Bq/L relative to surface water sources which may be attributed to the abundance of radionuclides in the soil. The annual effective dose accrued to all three categories of people (adults, children and infants) from the study areas posed no significant health threat to members of the public. This is because all the dose levels were found well below the permissible limits recommended by international health regulatory agencies. The values of radiation dose to internal organs due to inhalation of radon from the water samples were higher than the corresponding dose received by the stomach due to ingestion of radon leading to the possible occurrence of cancerous bronchial epithelium than stomach cancer. The obtained results in the present study could be used as baseline data for future research [36].

Periodic evaluation and monitoring of radon levels in drinking water sources by government agencies or interested researchers are strongly recommended to monitor any radiological health burdens that might arise from the consumption of water from the study areas. Water sources for consumption and other domestic applications from areas with dose levels above the acceptable limits should always be boiled irrespective of the source. This is to keep the activity concentration level as low as reasonably achievable to mitigate any associated radiological health issues from consumption of the water sources.

Acknowledgements

The authors are sincerely thankful to the Federal University of Health Sciences Otukpo, Benue State, Nigeria and the Government of the Federal Republic of Nigeria through the Tertiary Education Trust fund (TETFUND) for their financial support in the form of 2022/FX302 Institutional Based Research (IBR) grant.

References

1. Garba, N. N., Rabi'u, N., Yusuf, A. M., & Isma'ila, A. (2008). Radon: Its consequences and measurement in our living environs. Journal of Research in physical sciences, 4(4), 23-25.
2. Silas, A. (2017). Assessment of radon-222 in some selected water sources at Dustin-ma town, Dustin-ma local government area, katsina state.
3. Auvinen, A., Kurttio, P., Pekkanen, J., Pukkala, E., Ilus, T., & Salonen, L. (2002). Uranium and other natural radionuclides in drinking water and risk of leukemia:case–cohort study in Finland. Cancer Causes & Control, 13, 825-829.
4. Barnett, J. M., Holbert, K. E., Stewart, B. D., & Wayne, K. (1995). Lung dose estimates from 222Rn in Arizona groundwater based on liquid scintillation measurements. Health Physics, 68(5), 699-703.
5. Somlai, K., Tokonami, S., Ishikawa, T., Vancsura, P., Gáspár, M., Jobbágy, V., ... & Kovács, T. (2007). 222Rn concentrations of water in the Balaton Highland and in the southern part of Hungary, and the assessment of the resulting dose. Radiation measurements, 42(3), 491-495.
6. Jasaitis, D., & Pečiulienė, M. (2021). Natural Radioactivity and Radon Exhalation from Building Materials in Underground Parking Lots. Applied Sciences, 11(16), 7475.
7. USEPA. (1999). United States Environmental Protection Agency, Office of Water: 40 CFR Parts 141, and 142: National Primary Drinking Water Regulations; radon-222: proposed rule: US Environmental Protection Agency Washington, DC.
8. WHO, G. (2011). Guidelines for drinking-water quality. World health organization, 216, 303-304.
9. Kendall, G. M., & Smith, T. J. (2002). Doses to organs

and tissues from radon and its decay products. Journal of Radiological Protection, 22(4), 389.
10. Zhuo, W., Iida, T., & Yang, X. (2001). Occurrence of 222Rn, 226Ra, 228Ra and U in groundwater in Fujian Province, China. Journal of environmental radioactivity, 53(1), 111-120.
11. Etim, M. A., Babaremu, K., Lazarus, J., & Omole, D. (2021). Health risk and environmental assessment of cement production in Nigeria. Atmosphere, 12(9), 1111.
12. Ali, N., Khan, E. U., Akhter, P., Khan, F., & Waheed, A. (2010). Estimation of mean annual effective dose through radon concentration in the water and indoor air of Islamabad and Murree. Radiation protection dosimetry, 141(2), 183-191.
13. Bourai, A. A., Gusain, G. S., Rautela, B. S., Joshi, V., Prasad, G., & Ramola, R. C. (2012). Variations in radon concentration in groundwater of Kumaon Himalaya, India. Radiation protection dosimetry, 152(1-3), 55-57.
14. Chandrashekara, M. S., Veda, S. M., & Paramesh, L. (2012). Studies on radiation dose due to radioactive elements present in ground water and soil samples around Mysore city, India. Radiation protection dosimetry, 149(3), 315-320.
15. Khan, A. J. (2000). A study of indoor radon levels in Indian dwellings, influencing factors and lung cancer risks. Radiation measurements, 32(2), 87-92.
16. Khan, F., Ali, N., Khan, E. U., Khattak, N. U., & Khan, K. (2010). Radon monitoring in water sources of Balakot and Mansehra cities lying on a geological fault line. Radiation Protection Dosimetry, 138(2), 174-179.
17. Alharbi, W. R., Abbady, A. G., & El-Taher, A. (2015). Radon concentrations measurement for groundwater using active detecting method. Am. Sci. Res. J. Eng. Tech. Sci, 14, 1-11.
18. Nuhu, H., Hashim, S., Sanusi, M. S. M., & Saleh, M. A. (2020). Radon activity concentration measurements in water sources from Perak state Malaysia. Journal of Radiation Research and Applied Sciences, 13(1), 665-671.
19. Oni, E. A., Oni, O. M., Oladapo, O. O., Olatunde, I. D., & Adediwura, F. E. (2016). Measurement of radon concentration in drinking water of Ado-Ekiti, Nigeria. Journal of Academia and Industrial Research, 4(8), 190-192.
20. Ademola, J. A., & Oyeleke, O. A. (2017). Radon-222 in groundwater and effective dose due to ingestion and inhalation in the city of Ibadan, Nigeria. Journal of radiological protection, 37(1), 189.
21. UNSCEAR, S. (1993). Effects of ionizing radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, Report to the General Assembly, with Scientific Annexes, United Nations Publication Sales No. E 00 IX, 3.
22. UNSCEAR, S. (2000). Effects of ionizing radiation, Exposures from Natural Radiation Sources, Annex B. United Nations, New York.
23. Kumar, A., Kaur, M., Sharma, S., & Mehra, R. (2016). A study of radon concentration in drinking water samples of Amritsar city of Punjab (India). Radiation Protection and Environment, 39(1), 13.
24. Ravikumar, P., & Somashekar, R. K. (2014). Determination of the radiation dose due to radon ingestion and inhalation. International Journal of Environmental Science and Technology, 11, 493-508.
25. Garba, N., Rabi'u, N., Dewu, B., Sadiq, U., & Yamusa, Y. (2013). Radon assessment in groundwater sources from Zaria and environs, Nigeria. International Journal of physical sciences, 8(42), 1983-1987.
26. Chen, J. (2010). Doses to children from intakes by ingestion. Radiation protection dosimetry, 142(1), 46-50.
27. Folger, P. F., Nyberg, P., Wanty, R. B., & Poeter, E. (1994). Relationships between 222Rn dissolved in groundwater supplies and indoor 222Rn concentrations in some Colorado front range houses. Health physics, 67(3), 245-253.
28. Organization, W. H. (2009). WHO handbook on indoor radon: a public health perspective: World Health Organization.
29. Binesh, A., Arabshahi, H., & Pourhabib, Z. (2011). Radioactivity and dose assessment of heavy radioactive pollution, radon and radium from water sources of 3 northern regions in Iran. Int. J. Phys. Sci, 6(35), 7969-7977.
30. Nikolov, J., Todorovic, N., Forkapic, S., Bikit, I., & Mrdja, D. (2011). Radon in drinking water in Novi Sad. International Journal of Physical and Mathematical Sciences, 5(4), 539-542.
31. Ravikumar, P., & Somashekar, R. K. (2018). Distribution of 222Rn in groundwater and estimation of resulting radiation dose to different age groups: a case study from Bangalore City. Human and Ecological Risk Assessment: An International Journal, 24(1), 174-185.
32. Cho, J. S., Ahn, J. K., Kim, H. C., & Lee, D. W. (2004). Radon concentrations in groundwater in Busan measured with a liquid scintillation counter method. Journal of Environmental Radioactivity, 75(1), 105-112.
33. Xinwei, L. (2006). Analysis of radon concentration in drinking water in Baoji (China) and the associated health effects. Radiation protection dosimetry, 121(4), 452-455.
34. Darby, S., Hill, D., Auvinen, A., Barros-Dios, J. M., Baysson, H., Bochicchio, F., ... & Doll, R. (2005). Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case-control studies. Bmj, 330(7485), 223.
35. Khattak, N., Khan, M., Shah, M., & Javed, M. (2011). Radon concentration in drinking water sources of the Main Campus of the University of Peshawar and surrounding areas, Khyber Pakhtunkhwa, Pakistan. Journal of Radioanalytical and Nuclear Chemistry, 290(2), 493-505.
36. UNSCEAR, S. (2000). Report of the United Nations Scientific Committee on the effects of atomic radiation to the general assembly. ANNEX B Exposures from natural radiation sources.