DETERMINATION OF RADON CONCENTRATION AND THE ANNUAL EFFECTIVE DOSE DUE INHALATION FOR SOME BOREHOLE AND WELL WATER SUPPLY IN DUTSE, JIGAWA STATE NIGERIA

DANKAWU, U. M[1]; G. D. ADAMU[1]; M. N. MAHARAZ[1]; F. M. USMAN[1]; H. Y. SHUAIBU[1]; T. ZANGINA[1]; F. M. LARISKI[2]; M. AHMADU[4]; M. UZAIR[3]; A. YAKUBU; & S. S. ZARMA[1],
[1]Department of Physics, Federal University Dutse, P.M.B, 7156, Jigawa State, Nigeria.
[2]Department of Physics Yobe State University, Damaturu
[3]Department of Physics Sule Lamido University Kafin Hausa, Jigawa State Nigeria.
[3]Department of Chemistry, Federal University Dutse, P.M.B, 7156, Jigawa State, Nigeria.
Email: umdankawu@gmail.com **Phone No:** +234-703-836-4338, +234-802-725-4363

Abstract
Water remains the most abundant and critical commodity for guaranteeing the continuity of human life on earth. Ensuring cleanliness of water for human consumption is of paramount importance. The ^{222}Rn concentration has been assessed in drinking water samples collected from twenty-two (22) different water sources, used by communities around Dutse Local Government Area, Jigawa State Nigeria, with the view of assessing the radiological risk, if any, to human health. The sources of water samples collected were borehole and local hand dug wells. Radon concentration was Determined using liquid scintillation counter (Model: Tri-CarbLSA1000) following standard procedures. The ^{222}Rn concentration ranged from 31.22871 to 273.2171 BqL^{-1} and 32.6987 to 155.9374 BqL^{-1} with mean value of 82.7461 and 94.10771 BqL^{-1} for boreholes and well water samples respectively. These values were found to be above the recommended benchmarks prescribed by UNSCEAR, WHO, but below European commission standard. The annual effective dose due inhalation from the corresponding radon concentration for borehole and local hand-dug well water sample were ranged from 0.078696 to 0.688507, and 0.082401 to 0.636197 mSv/y respectively. The mean values for both boreholes and well water samples were found to be 0.20852 and 0.237151 mSv/y respectively. All the mean values of the annual effective dose by inhalation were above the recommended level of 0.1 mSv/y set by World Health Organization (WHO, 2004). Also, the excess life cancer risk due to inhalation of radon in the water samples were found to be in the range of 2.75×10^{-4} to 2.41×10^{-3} and 2.88×10^{-4} to 2.227×10^{-3} with the overall mean value of 7.3×10^{-4} and 8.3×10^{-4}, for borehole and local hand-dug well water sample respectively. All these values were below the acceptable cancer risk value as recommended by United States Environmental Protection Agency (USEPA, 1999). *So, the water under this study area need to be examine before use.*

Keyword: ^{222}Rn Concentration Annual effective dose, excess life cancer risk, Drinking water, Dutse

Introduction
Water is one of the most significant resources to humans and every other life (Shittu *et al.,* 2016). Several studies have been carried out to assess the quality of drinking water in Nigeria. And yet the assessment of water contamination remains significant especially in Dutse local government Area, the capital city of Jigawa state (Dankawu *et al.*, 2021). There are two sources of water: rain and ground waters. It is found in rivers, wells, lakes and streams. Surface water that penetrated into the ground, filling soil pores spaces, fissures, fractures of the lithological formations, among others, is known as groundwater (Chifu *et al.,* 2016). The presence of natural radioactivity in ground, surface and domestic water has been studied with great efforts in many

countries of the world by many investigators. The production of man-made radionuclides a result of fission process and by accelerating electrically charged sub nuclear particles such as protons, deuterons, tritium and alpha particles to very high energies and directed onto a target material thereby causing nuclear reactions that results in the formation of radionuclides. (Tchokossa *et al.,* 1990). The significant of water resource to humans and every other life is always becoming more and more necessity to man and his environment; because it has existed throughout the history of the earth crust or even before the existence of man. Man uses water for the following activities: irrigation, power generation and domestic activity. Water pollution arises as a result of waste and sewage disposal into the environment and rivers by industries, hospitals and use of materials such as fertilizers by farmers. These disposed materials often contain radio nuclides (Shittu *et al.,* 2016).

Radon, the heaviest element of the noble gases in the periodic table of elements, is a natural radioactive element that can be found on water, soils and rocks (Inacio, *et al.,* 2017) Radon is a naturally occurring radioactive inert gas, with atomic number 86. Radon has over twenty-six isotopes, the most important isotopes in terms of their radiological significance are: ^{222}Rn (radon) and ^{220}Rn (thoron). Being decay products of the primordial radioactive elements, uranium and thorium, respectively, ^{222}Rn and ^{220}Rn are ubiquitous in all human environments. Most of the radon to which people are exposed emanates from soil and rock. The other sources of significance are building materials, potable water, and natural gas (UNSCEAR, 1993). The link between residential radon and lung cancer among the general public is not unequivocal (Mustapha *et al*., 2002). Dissolved radon is easily released into the air when the water is used for showering, cleaning and other everyday purposes in homes. Only about 1–2 % of radon in the air comes from drinking water. However, breathing radon released to air from tap water increases the risk of lung cancer. Some radon stays in the water; drinking water containing radon also presents a risk of developing internal organ cancers, primarily stomach cancer (Asha *et al*., 2012). However, this risk is smaller than the risk of developing lung cancer from radon released to air from tap water (USEPA, 1999).

Many studies have been carried out on evaluation of radon and estimated annual effective dose in drinking water within and outside Nigeria. However, there is little data on radon recorded in the north western part of Nigeria. This is due partly to the fact that measurements of radon are done without estimation of annual effective dose and excess lifetime cancer risk. The aim of this study is to determine radon concentration for some selected boreholes and well water in Dutse Local Government Jigawa State, Nigeria. The specific objectives of the study are to examine the radon concentration, the annual effective dose due to inhalation and excess lifetime cancer risk.

Study Area

The area under study is the Dutse Local Government Area, Jigawa state, Nigeria. Dutse is located between Latitudes 11^0 38' 31''N and 11°46' 16''N and longitudes 9^{0}18' 33''E and 9^{0}24' 24''E. It is bordered by Ringim and Jahun Local Government Areas to the North, Birnin Kudu Local Government Areas to the South, Kiyawa and Gaya Local Government Areas to the East and West respectively (Aminu, 2015**)**. The estimated population of Dutse in 1991 was 138,451 people (Dankawu *et al*., 2021). This comprises of 68,975 males and 69,476 females (NPC, 1991). Based on the 2006 census, Dutse has a population of 251,135, with 125,773 males and 125,362 females (NPC, 2006). The climate of Dutse is tropical wet dry climate (Koppen AW) classification and the temperature is warm to hot throughout the year, even though there is slightly cool period around November through February. The mean annual temperature is 26^{0}C but, mean monthly value ranges between 21^{0}C in the coldest months (December/February) and 310C in the hottest months (April/May) (Aminu, 2015).

Materials and Method

Method of Sample Collection: A total of twenty-two (22) water samples were collected in eleven different wards under Dutse local Government Area. Two samples from each ward (one sample for both borehole water and local hand dug-well), making eleven sample for both borehole water and local hand dug-well from different parts of Dutse local government Area respectively. All the water sample were obtained during dry season, the sample were collected in a cleaned 750 ml plastic faro bottles and analyzed for ^{222}Rn concentration. The 750 ml plastic faro bottle were first washed and rinsed with distilled water to avoid radon present in the sample from being contaminated, Samples from hand dug wells were collected with the aid of bailers, with the stagnant water in the wells first been purged severally by drawing it out and allowing the wells to refill in order to assure that fresh samples were obtained, while Samples from boreholes were operated for at least four minutes prior to collection. This is to ensure fresh samples are obtained. The bottles were filled to the brim to prevent CO_2 from being trapped and dissolving in water which may affect the chemical content, and then closed immediately to avoid loss of radon by degassing during transport to the laboratory. Concentrated Trioxonitrate (V) acid HNO_3 was added to the water to ensure radionuclides remain in solution, rather than adhering to the walls of the container. All samples were transported to the Center for Energy Research and Training, Ahmadu Bello University Zaria (CERT) for preparations and analysis. Dosimeter were used to measure the background radiation of each sample location

Sampling Preparation: About 10 mL of each sample was added into a scintillation vial containing 10 mL of insta-gel scintillation cocktail. The vials were tightly sealed and then shaken thoroughly for three minutes to extract ^{222}Rn in the water phase into the organic scintillator.

Method Sample Analysis: The prepared samples were analyzed using a well calibrated Liquid Scintillation Counter (Tri-Carb-LSA1000) located at the Center for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. The samples were analyzed three hours after preparation, to allow for radioactive equilibrium between ^{222}Rn and its daughter progeny to be established. Calibration of the liquid scintillation counter was made using IAEA ^{222}Ra standard solutions. The activity concentration ^{222}Ra was calculated using the equation 2.1 (Abba *et al.,* 2020).

$$Rn(\mathrm{Bq/L} = \frac{100\times(R_n\times R_0)\exp(\lambda t)}{60\times5\times0.964} \quad (2.1)$$

where Rn (Bq/L) is ^{222}Rn concentration at the time of sample collection (Bq/L), R_n is the sample total count rate (count min^{-1}), R_o is the background count rate (count min^{-1}), t is the elapsed time between sample collection and counting (4320 min. (3days), λ is ^{222}Rn decay factor (1.26×10^{-4} min^{-1}), 100 is a conversion factor from per 10 ml to per liter (l^{-1}), 5 is the number of emissions per count; 60 is conversion factor from min. to s. And 0.964 is the fraction of ^{222}Rn in the cocktail in a vial of 22 ml total capacity, assuming it contains 10 ml cocktail, 10 ml water and 2 ml air.

Annual Effective Dose

The annual effective dose due to inhalation of radon in water was calculated using equation (2.2) below as proposed by the United Nation Scientific Committee on the Effects of Atomic Radiation (Malakootian *et al.*, 2017).

$$C_{inh} = \frac{C_{Rn} \times R_W \times F \times T \times DF}{1000} \quad (2.2)$$

where, C_{inh} is the annual effective dose ($mSvy^{-1}$) from inhalation of radon release from water in to air, C_{Rn} is the ^{222}Rn concentration in water (Bq/L), R_w is the ratio of radon released to air when water use to radon in water (10^{-4}), F is the equilibrium factor between radon and its product (0.4), T is the average residence time of individual in the in the interior (7000h/y), DF is the conversation dose factor 9_nSv $(Bqhm^{-3})^{-1}$, 1000 is the conversation factor micro Sievert to mile Sievert.

Result and Discussion

Table 1 and Fig. 1 show the data of sample ID, Coordinates of the Sampling Location, ^{222}Rn Concentrations in Bq/l and annual effective dose due to inhalation and excess life cancer risk for borehole water sample. The ^{222}Rn concentrations (BqL^{-1}) of borehole water sample ranged from 31.22871 BqL^{-1} as the lowest value obtain from UMD08 to 273.2171 BqL^{-1} as the highest value obtained from UMD04 with the mean value of 82.7461 BqL^{-1}. The annual effective dose from inhalation of borehole water sample were found in the range of 0.078696 $mSvY^{-1}$ as the lowest value obtained from UMD08 to 0.688507 $mSvY^{-1}$ as the highest value obtained from UMD04 with mean value of 0.20852 $mSvY^{-1}$. The excess life cancer risk from annual effective dose due to inhalation were found to be in the range of 2.75 x 10^{-4} as the lowest value obtained from UMD08 to 2.41 x 10^{-3} as the highest value from UMD04 with a mean value of 7.3 x 10^{-4}.

Table 1: Coordinates of the sampling location ^{222}Rn Concentration, Annual Effective Dose and Excess Life Cancer Risk for Borehole Water Sample

Sample ID	Latitude	Longitude	^{222}Rn Conc. (BqL^{-1})	C_{inh} ($mSvY^{-1}$)	$ELCR_{inh}$
UMD 01	N 11°54'53.39"	E 9°23'21.92"	46.02753	0.115989	4.06 x 10^{-4}
UMD 02	N 11°51'01.38"	E 9°15'40.16"	38.5289	0.097093	3.4 x 10^{-4}
UMD 03	N 11°50'48.79"	E 9°12'09.96"	74.6818	0.188198	6.59 x 10^{-4}
UMD 04	N 11°41'32.69"	E 9°19'04.88"	273.2171	0.688507	2.41 x 10^{-3}
UMD 05	N 11°41'04.92"	E 9°14'39.68"	75.43685	0.190101	6.65 x 10^{-4}
UMD 06	N 11°37'55.95"	E 9°20'49.56"	131.2359	0.330714	1.158 x 10^{-3}
UMD 07	N 11°40'17.02"	E 9°24'41.53"	32.212	0.081174	2.84 x 10^{-4}
UMD 08	N 11°43'32.13"	E 9°20'39.24"	31.22871	0.078696	2.75 x 10^{-4}
UMD 09	N 11°44'59.03"	E 9°20'30.44"	71.18606	0.179389	6.28 x 10^{-4}
UMD 10	N 11°49'19.84"	E 9°19'01.78"	33.84086	0.085279	2.98 x 10^{-4}
UMD 11	N 11°50'41.41"	E 9°18'21.09"	102.6114	0.258581	9.05 x 10^{-4}
MEAN			82.7461	0.20852	7.3 x 10^{-4}

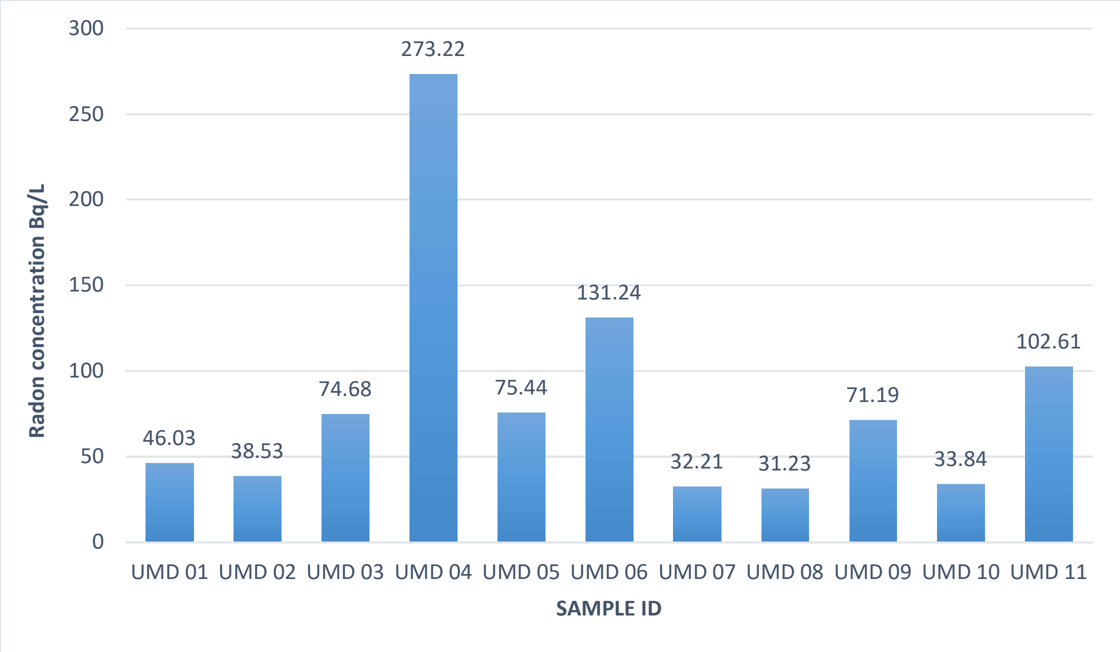

Fig.1: Chart of radon concentration in Bq/l for borehole water samples in Dutse Town (Capital City of Jigawa State, Nigeria).

Table 2 and figure 2 show the data of sample ID, Coordinates of the sampling Location, ^{222}Rn concentrations Bq/l and annual effective dose due to inhalation and excess life cancer risk for local hand-dug well water samples. The ^{222}Rn concentrations in (BqL^{-1}) of local hand-dug well water sample ranged from 32.6987 BqL^{-1} as the lowest value obtained from UMD21 to 155.9374 BqL^{-1} as the highest value obtain from UMD14 with the mean value of 94.10771 BqL^{-1}, the annual effective dose from inhalation of local hand-dug well water sample ranging from 0.082401 $mSvY^{-1}$ as the lowest value obtained from UMD21 to 0.636197 $mSvY^{-1}$ as the highest value obtained from UMD15 with mean value of 0.237151 $mSvY^{-1}$. And the excess life cancer risk from annual effective dose due to inhalation were found to be in the range of 2.88×10^{-4} as the lowest value obtain from UMD21 to 2.227×10^{-3} as the highest value obtained from UMD15 with an average value of 8.3×10^{-4}.

Table 2: Coordinates of the sampling location ^{222}Rn Concentration, Annual Effective Dose and Excess Life Cancer Risk for Local Hand-Dug Well Water Sample

Sample ID	Latitude	Longitude	^{222}Rn Conc. (BqL^{-1})	C_{inh} ($mSvY^{-1}$)	$ELCR_{inh}$
UMD 12	N 12°00'28.14"	E 9°21'25.17"	39.95914	0.100697	3.52×10^{-4}
UMD 13	N 11°49'17.31"	E 9°15'43.96"	48.80875	0.122998	4.3×10^{-4}
UMD 14	N 11°50'50.06"	E 9°10'40.66"	155.9374	0.392962	1.375×10^{-3}
UMD 15	N 11°41'15.78"	E 9°19'50.91"	252.4589	0.636197	2.227×10^{-3}
UMD 16	N 11°41'11.58"	E 9°15'24.74"	119.3673	0.300806	1.053×10^{-3}

UMD 17	N 11°40'43.63"	E 9°20'13.39"	81.64469	0.205745	7.2×10^{-4}
UMD 18	N 11°41'42.09"	E 9°23'11.31"	47.22953	0.119018	4.17×10^{-4}
UMD 19	N 11°41'05.63"	E 9°21'04.86"	77.13526	0.194381	6.8×10^{-4}
UMD 20	N 11°44'18.08"	E 9°20'53.33"	75.8838	0.191227	6.69×10^{-4}
UMD 21	N 11°44'54.06"	E 9°13'39.46"	32.6987	0.082401	2.88×10^{-4}
UMD 22	N 11°50'57.06"	E 9°18'36.49"	104.0613	0.262235	9.18×10^{-4}
MEAN			94.10771	0.237151	8.3×10^{-4}

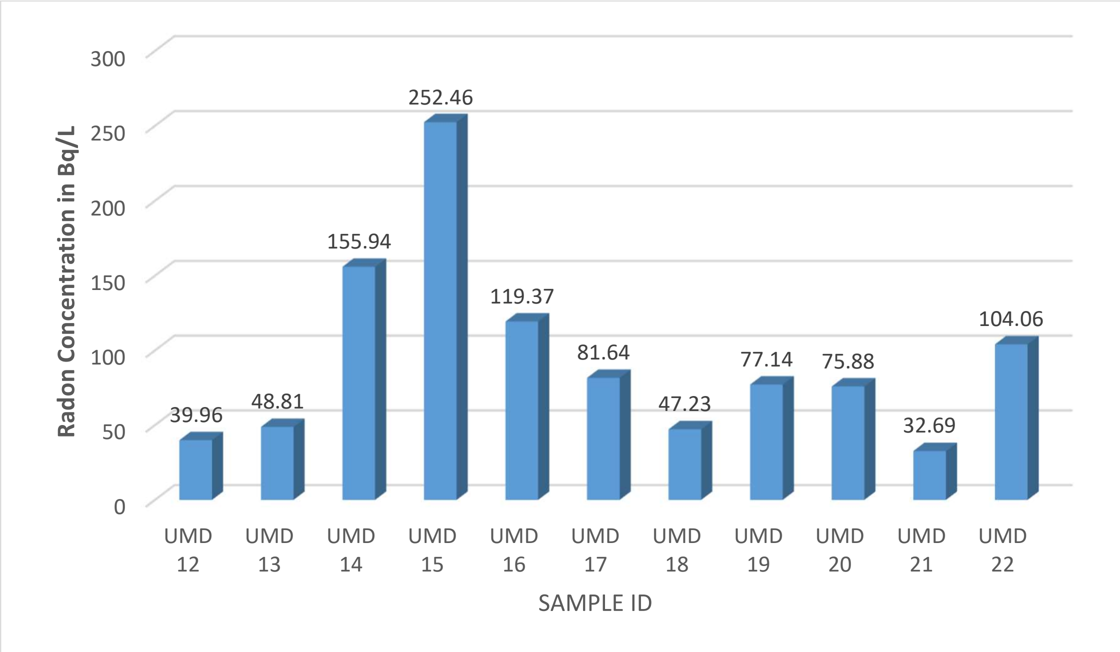

Figure 2: Chart of radon concentration in Bq/L for local hand-dug well water samples in Dutse Town (the Capital City of Jigawa State, and Nigeria)

Table 3 and Figure 3 show the comparison of ^{222}Rn concentration from Dutse Local Government Area, Jigawa State, Nigeria with other parts of Nigeria. This clearly show that the result obtained in this study was higher than all the compared value, impact the value of this study is 7.83 times higher than that of Kaduna and 6.74 times than higher that of Zaria.

Table 3: Comparison of ^{222}Rn Concentration from Dutse with Other Parts of Nigeria

Locations	^{222}Rn Concentration (Bq/L)	Sources
Kaduna	10.69	(Garba and Hussaini, 2018).
Zaria	12.43	(Garba *et al.*, 2017).
Sokoto	34.00	(Abba *et al.,* 2020).
Jos	17.00	(Aminu, 2020).
Dutsinma	64.66	(Adams, 2017).
Dutse	83.77	(Current study, 2021)

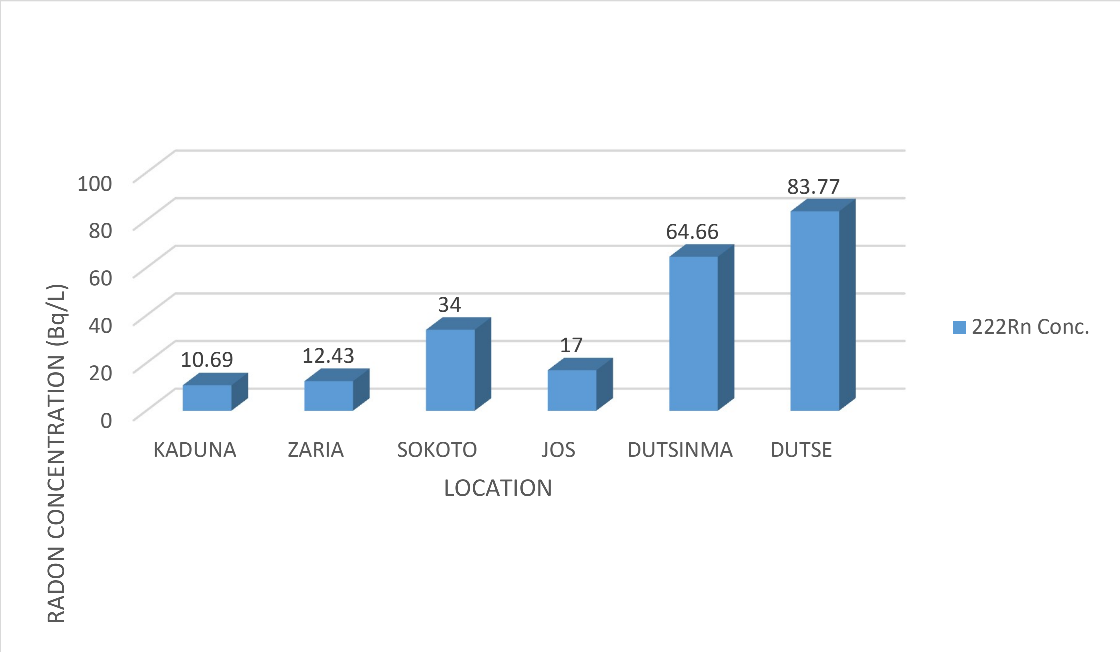

Figure 3: Relationship between ^{222}Rn Concentration from Dutse with other part of Nigeria

Table 4 and Figure 3 shows the comparison of ^{222}Rn concentration from Dutse Local Government Area, Jigawa State, Nigeria with others Countries. This clearly show that the result obtained in this study was higher than all the compared value, impact the value of this study is 69.81 times higher than that of Iran and 34.904 times than higher that of Turkey.

Table 4: Comparison of ^{222}Rn Concentrations from Dutse with Other Countries

Countries	^{222}Rn Concentrations (Bq/L)	Sources
India	4.42	(Sudhir *et al.*, 2016).
Malaysia	14.7	(Nasar *et al.*, 2015).
Iran	1.2	(Malakootian *et al.*, 2017)
Turkey	2.4	(Tabar and Yakut, 2014)
Dutse	83.77	(Current study, 2021)

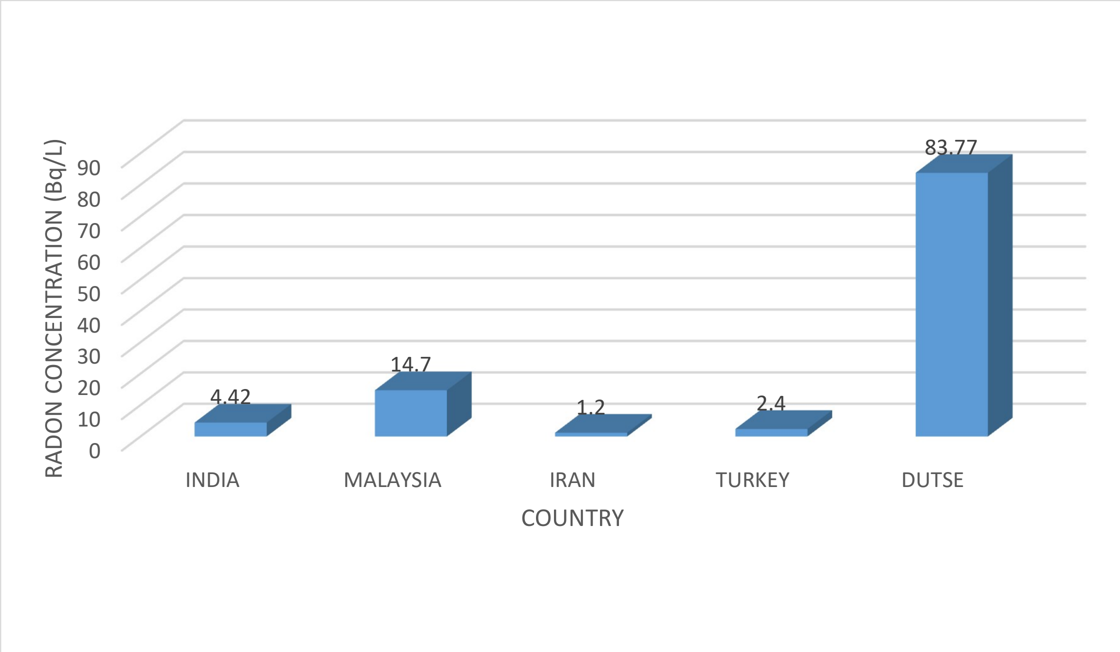

Figure 4: Relationship between ^{222}Rn Concentrations from Dutse Local Government Area Jigawa State Nigeria with others Countries

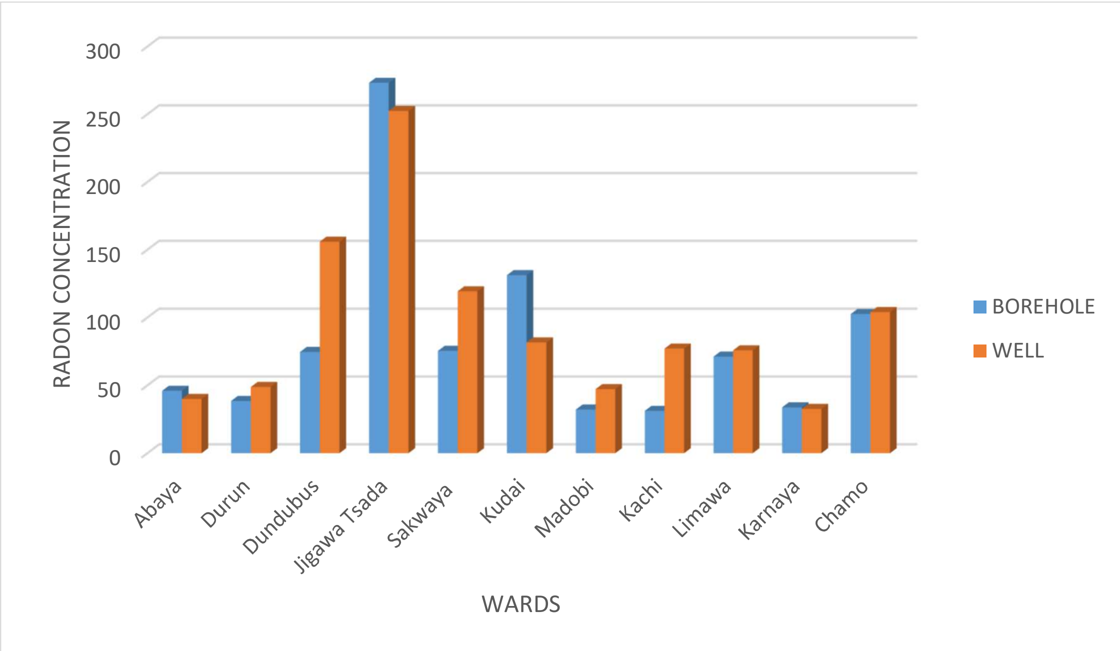

Figure 5: Comparison of radon concentration for borehole and local hand dug-well water sample collected from different wards in Dutse Local Government Area, Jigawa State

It was clearly shows that 63.64% of well water sample were higher than the borehole water sample however only 36.36% of borehole water sample are higher than well water sample.

Discussion

The radon concentration in drinking water samples collected from Dutse Local Government Area, Jigawa state, Nigeria were studied and analyzed using Microsoft excel application. The study covered radon concentration, estimated annual effective dose from inhalation and estimated excess life cancer risk due to annual effective dose from inhalation and comparing radon concentration and annual effective dose with other research studies within and outside Nigeria.

The study found that from Table 1 and Table 2 the ^{222}Rn concentrations in (BqL^{-1}) for borehole and local hand-dug well water sample ranged from 31.22871 BqL^{-1} to 273.2171 BqL^{-1} and 32.6987 BqL^{-1} to 155.9374 BqL^{-1} respectively. The mean concentration of the ^{222}Rn concentration in all the water samples was found to be 82.7461 BqL^{-1} and 94.10771 BqL^{-1} for borehole and local hand-dug well water supply respectively. These values are above the Maximum Concentration Limit (MCL) of 11.1Bq/L as set by USEPA (1999), world average value of 10Bq/L (WHO, 1993; UNSCEAR, 2002) and 11.1 BqL^{-1} set by the Standard Organization of Nigeria (SON, 2003). But all the mean were found to be below the recommended action level of 100 BqL^{-1} set by European Commission recommendations on the protection of the public against exposure to radon in drinking water supplies (2001/928/Euratom), for public water supplies and the World Health Organization (EU 2001; WHO, 2008), impact only seven (7) location from borehole and local hand-dug well water sample out of twenty two (22) water sample were above WHO accepted value, namely (UMD04, UMD06, UMD11 and UMD14, UMD15, UMD16, UMD22. However only few areas namely UMD02, UMD07, UMD08, UMD10 and UMD12, UMD21 from borehole and local hand-dug well water sample where below 4.0-40.0 BqL^{-1} (UNSCEAR 2008). This finding was not in accordance with study carried out by Garba and Hussaini, (2018), who found average radon concentration of 10.69 ± 0.39 Bq/L, and with study carried out by Garba *et al.*, (2017), who found mean radon concentration of 12.43 Bq/L and 11.16 Bq/L. with study carried out by (Abba *et al.*, (2020) and they found mean ^{222}Rn concentration to be 34±3.7 Bq/L. The finding is slightly in accordance with study carried out by Adams, (2017), who found mean radon concentration to be 64.66 Bq/L, 41.15 Bq/L and 34.57 Bq/L for Borehole, open well and Earth-Dam respectively.

The annual effective dose by inhalation from the corresponding radon concentration for borehole water sample ranged from (0.078696 to 0.688507), while local hand-dug well water sample ranged (0.082401 to 0.636197) mSv/y. With overall mean value of (0.20852 and 0.237151) mSv/y for borehole and local hand-dug well water sample respectively. All the mean values of the annual effective dose by inhalation were above the recommended level of 0.1 mSv/y set by World Health Organization (WHO, 2004). However, some few areas namely (UMD01, UMD02, UMD07, UMD08, UMD10) and (UMD12, UMD13, UMD18, UMD21) for borehole and local hand-dug well water sample were found to be below the recommended level of 0.1 mSv/y set by World Health Organization (WHO, 2004). Excess life cancer risk (ELCR) by inhalation from the corresponding annual effective dose for borehole and local hand-dug well water sample were found to be in the range of 2.75×10^{-4} to 2.41×10^{-3} and 2.88×10^{-4} to 2.227×10^{-3} with the overall mean value of 7.3×10^{-4} and 8.3×10^{-4}, for borehole and local hand-dug well water sample respectively.

Conclusion

Health hazard from exposure to radon is not an acute problem if considered globally. However, a looming danger of health complications cannot be ignored due to the health risks involved in areas where radon concentration assumes dangerous proportions. The present study showed that the mean radon concentration in borehole and local hand-dug wells water samples from the study areas were above the maximum contaminant level (MCL) value. Also, the study shows annual effective dose due to inhalation and excess life cancer risk from corresponding annual effective dose due to inhalation for borehole and local hand-dug wells water samples values were varying with respect to the increase in radon concentration and were significantly higher than the 0.1 mSv/y as set by earlier studies (UNSCEAR; WHO, 2004 and EU, 1998). Hence further extensive studies should be done on large scale by initiating further detailed investigation of whole command area completely for radon contamination, to increase awareness and mitigate possible hazards.

References

Abba, L., Nasiru, R., Garba, N. N., & Ahmed, Y. A, (2020). Assessment of annual effective dose due to inhalation and ingestion of radon in water samples from the cement industrial area of Sokoto, North-Western Nigeria. *FUDMA journal of science 4(*1), 615– 619.

Adams, S. (2017). Assessment of radon-222 in some selected water sources at Dutsin-Ma town, Dutsin-Ma Local government area, katsina state. *FUDMA Journal of Science, 6*(2) 147 – 153.

Aminu, K. (2020). Measurement of radon concentration in borehole and well water, and estimation of indoor radon levels in Jos, Plateau State, Nigeria. *International Journal of Pure and Applied Science, 19* (9), 82-96.

Aminu, S. Z. (2015), Land use land cover changes in Dutse (1986-2014), Jigawa state, Nigeria. Unpublished Master's Thesis, Department of Geography, Faculty of Science Ahmadu Bello University, Zaria Nigeria.

Asha, R., Rohit, M., & Vikas, D. (2012). Radon monitoring in groundwater samples from some areas of Northern Rajasthan, India, Using a Rad7 Detector. *Radiation Protection Dosimetry, 22,* 1-6. http://rpd.oxfordjournals.org/.

Chifu, E., Ndikilar, S. A., & Daniel, K. A. (2016). Determination of radioactivity concentration and estimation of annual effective dose for all age categories of drinking water collected from Dutse Town, Nigeria. *Journal of Applied Physics (IOSR-JAP),8,*13-22 www.iosrjournals.org.

Dankawu, U. M., Shuaibu., H Y., Maharaz, M. N., Zangina, T., Lariski, F. M., Ahmadu, M., Zarma, S. S., Benedict, J. N., Uzair, M.,, Adamu, G. D., & Yakubu, A. (2021). Estimation of excess life cancer risk and annual effective dose for boreholes and well water in Dutse, Jigawa State Nigeria. *Dutse Journal of Pure and Applied Sciences (DUJOPAS), 7* (4), 113-122.

EU. (European Commission, 2001). Commission recommendation of 20th December 2001 on the protection of the public against exposure to radon in drinking water. 2001/982/Euratom, L344/85.Official Journal of the European Commission.

EU. (European Commission, 1998). European drinking water directive 98/83/EC of 3rd November 1998 on the quality of water intended for human consumption. Official J L 330. Official. *Journal of the European Commission.*

Garba, N. N., Rabi'u, N., Dewu, B. B. M., Sadiq, U., Kutama, H.A. (2017). Annual effective dose due to 222rn concentration in well and borehole water source of Zaria and environs, Nigeria. Yusuf Maitama Sule University, Kano Faculty of Science 3rd Annual International Conference.

Garba, Z. N., & Hussaini, A. R. (2018). Assessment of radon concentration in underground well water from selected parts of Kaduna Metropolis. *Chem Search Journal, 9(2), 8 – 12.*

Inacio M., Soares, S., Almeida, P. (2017). Radon concentration assessment in water sources of public drinking of Covilh, Portugal. *Journal of Radiation Research and Applied Sciences, 10,* 135e139*.*

Mustapha, A. O., Patel, J. P., & Rathore, V. S. (2002). Preliminary report on radon concentration in drinking Water and indoor air in Kenya. *Environmental Geochemistry and Health,24,* 387–396.

Malakootian M, and Y. Soltani Nejhad ID, (2017). Determination of radon concentration in Drinking Water of Bam villages and evaluation of the annual effective dose. *International Journal of Radiation Research, 15*(1), 112-124.

Nisar, A., Mohammad, S. J., & Mohammed, S. A. (2012). Study of radon Concentration and toxic Elements in drinking and irrigated water and its implications in Sungai Petani, Kedah, Malaysia *Journal of Radiation Research and Applied Sciences 8 294e299*. http://www.elsevier.com/locate/jrras

Shittu, A., Chifu, E., Ndikilar, A. B., Suleiman, H., & Hafeez, Y. (2016). Assessment of heavy metals and radioactivity concentration in drinking water collected from local wells and boreholes of Dutse Town, North West, Nigeria. *Journal of Environment Pollution* and *Human Health, 4*(1), 1-8.

Shittu, A., Chifu, E., Ndikilar, A. B., Suleiman, H., Hafeez, Y. (2016). Evaluation of radioactivity concentration in drinking water collected from local wells and boreholes of Dutse Town, North West, Nigeria. *International Journal of Environmental Monitoring and Analysis, 4*(1), 6-11.

SON. (2003). Standard Organization of Nigeria (Inorganic constituents for drinking water Quality).

Sudhir M., Asha, R., & Rohit, M. (2016). Estimation of radon concentration in soil and groundwater samples of Northern Rajasthan, India, *Journal of Radiation Research an Applied Sciences, 9(*2), 125- 130.

Tabar, E., & Yakut, (1993) (2014). Radon measurements in water samples from the thermal springs of Yalova Basin, Turkey. *Journal of Radioanal Nucl Chem 299,* 311–319.

Tchokossa P., J. B., & Olomo, O. A. O. (1999). Radioactivity in the community water supplies of Ife-Central and Ife-East local government areas of Osun State, Nigeria.

UNSCEAR, (United Nations Scientific Committee on the Effects of Atomic Radiation, 1993): *Sources and effects of ionizing radiation.* UNSCEAR report to the General assembly with scientific annexes, Volume II. New York: United Nation.

UNSCEAR, (United Nations scientific committee on the effect of atomic radiation, 2002). *Sources and effects of ionizing radiation.* Report to general assembly with annexes. United Nations New York: United Nations Sales Publications.

USEPA, (United States environmental protection agency, 1999). Health risk reduction and cost Analysis for radon in drinking water. *Federal Register, Washington D.C. 64*(38), 9559. Washington.

WHO. (2008) World health organization. *Guidelines for drinking water quality.* Incorporating first and Second Addenda 3rd ed. WHO press, Geneva. Switzerland.

WHO. (1993). World Health Organization. *Guidelines for drinking-water quality.* Vol.1, 2nd ed World Health Organization, Geneva.

WHO. (2004). (World health organization). *Guidelines for drinking water quality*. Vol. 1 3rd ed. World Health Organization.