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Health Risk Assessment of Human Exposures to Radiation Emanating from Radon in Groundwater from Parts of Damaturu Metropolitan Yobe State, Northeastern Nigeria

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Abstract-Groundwater is an important and vital water resources, its demand had increased due to increase in population and enhanced standards of living. In this study a total of 30 water samples from borehole and well water were analyzed using Rad7 (Durrige) radon detector to determine radon concentration from parts of Damaturu metropolitan. The data generated was then used to evaluate radiological hazards posed to the public. The radon (Rn-222) concentration in the surface water varied from 0.35 to 3.08Bq/L with a mean value of 1.23±0.09Bq/L against the global average of 11Bq/L and thoron (Rn-220) was not detected in the ground water. In other to assess hazards due to radon concentration in the water to the people, the annual effective doses (AED) were computed. For ingestion of radon in water the AED varied from 1.14 to 7.86μSv/y with a mean value of 3.11±0.34 μSv/y while inhalation of radon from water varied from 1.03 to 8.57μSv/y with a mean value 1.26±0.28 μSv/y respectively. The total AED due to ingestion and inhalation of radon in water ranged from 1.10 to 5.87μSv/y with a mean value of 1.14±0.38 μSv/y. The results for water radon concentration have shown that people are safe for using the water for drinking, cooking bathing and other domestic purposes.

***Keywords:** Radon concentration, Groundwater, Radiation Dose, Rad 7*

I. INTRODUCTION

Health-related problems are often linked to higher levels of radon concentration in groundwater compared to the surface water [1]. Radon and its short lived decay products are responsible for about 55% of the total background radiation exposure of the general public [2]. Movement of Radon is majorly caused by diffusion or by transport processes of gaseous or liquid phases and disequilibrium between (Rn-222) and other uranium series is due to the diffusive escape of Rn-222 [3]. Groundwater can either be extracted from bedrock (drilled wells) or from soil aquifer (dug well). Private wells are often drilled or dug to supply water to individual household that are not connected to public water supply in Damaturu. In United State of America, people with private wells must carry out test on the their well water to ensure that radon levels meet EPA's standard (EPS's Action Level of 150Bq/m3,[4]

In Nigeria several scientist have conducted research on concentration of radon in groundwater and its effects on human heath ([3]; [5] ; [6] and [7] reported that all the water samples assayed for radon concentration are not safe for domestic purposes and consumption. It is expected that the people of Idah and its environs may likely suffer from stomach cancer, lung cancer, leukemia, chronic diseases etc. because of the high ^{222}Rn concentration in ground water.

[8]. The availability of radon concentration measured in different states in southwestern Nigeria exhibits variations that may be attributed to different geological structures and building materials from different sources with interest ventilation condition and presence of nearby fault line and environmental influence. The value of radon concentration in soil varies from 3Bq/Kg – 2332Bq/m^3. The study shows that some factors contribute the high value of radon concentration in soil and all the sample values are below the permissible level < 2.7 PCi/L, risky level 2.7 –4.0 PCi/L and critical threshold level >4 PCi/L. The purpose of this study is to is to assess ^{222}radon concentration in borehole, well water and estimation of resulting radiation dose n human health in parts of damaturu metropolitan yobe state. The objectives include evaluation of annual effective dose (AED) due to ingestion and inhalation of borehole and well

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water in Damaturu and estimation of total AED due to ingestion and inhalation of radon in water.

II. MATERIALS AND METHODOLOGY

Study Area

The study area Damaturu metropolis, is the administrative headquarters of Yobe State which lies between the latitudes of 11° 44' and 11° 44' N and longitudes of 11° 56' and 11° 58' E and in the north eastern region of Nigeria. As shown in figure 1. It covers a total land area of 2,366 km² and a population of 88,014 according to 2006 census data (NPC, 2006). The city being on the A3 highway was estimated to have a population of 44,268 by 2010.

The metropolis is located in the semi-arid region of Nigeria with tropical continental climate. The climate is characterized by short wet season (June to August) and long dry season (October to May) with high temperature throughout the year. Annual rainfall is usually low, while evaporation is high. Damaturu is a water deficit region with very low surface water during the rainy season. Damaturu is not drained by any river, hence absence of surface water resources. The town depends mainly on underground water resources which are usually accessed through drilling of borehole and artesian wells.

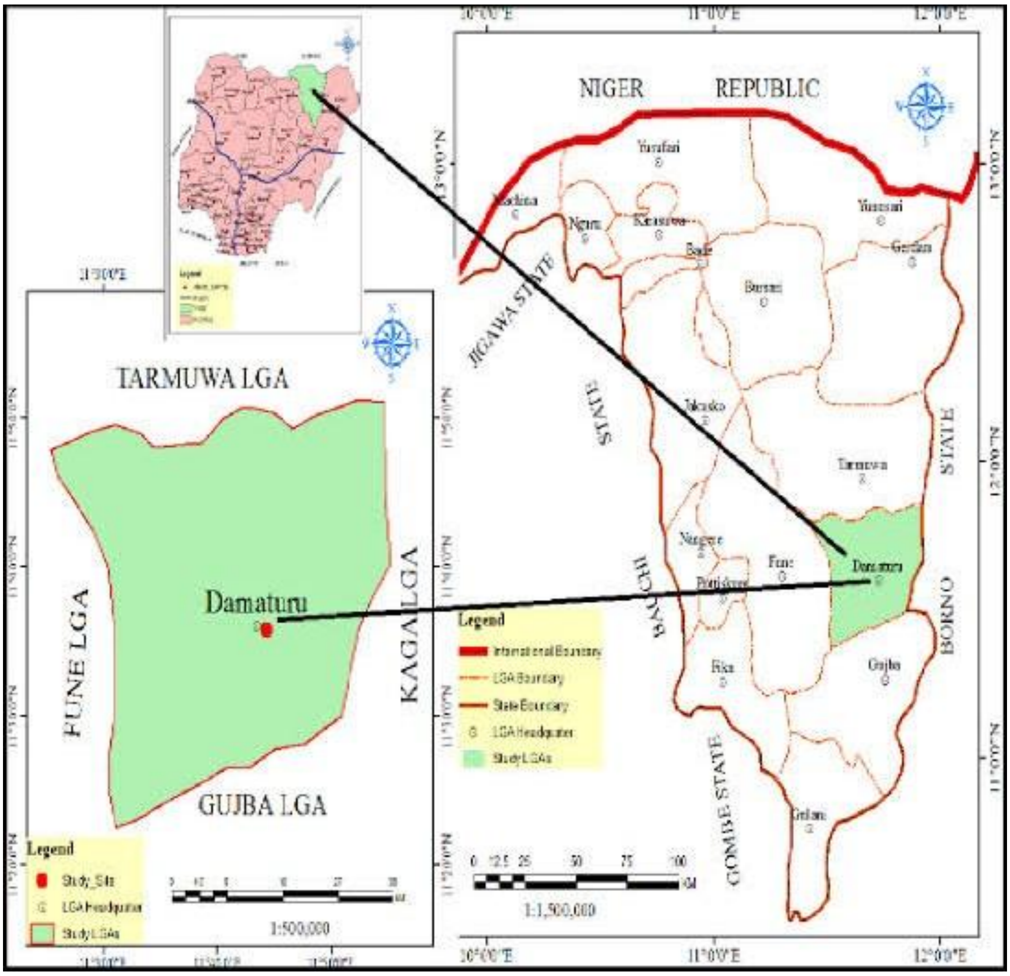

Fig .1: Map of the study area showing sample location

Geological formations of Damaturu

The study area is a part of the sediments of the Chad Basin comprising such rock types as, sands and sandstones, clay/shale intercalations. The Chad formation dips concentrically at about 1.5m/Km towards Lake Chad. The formation varies rapidly both laterally and vertically. Often diatomite is found within the clayey zones. The geological sequences are such that sandy units are confined by subjacent and superjacent clay beds leading to pressure water in a number of places. Geophysical evidence is reported to show that the underlying basement is irregular and carries a major trough running WSW-ENNE from Damaturu and joined by two minor troughs from the northwest. These are filled by

Cretaceous sediments while on their flanks the Chad Formation overlies the basement directly [9] and [10]

Structurally the formation is generally simple with little complicated geological features. Generally, the water bearing zones are often described as Upper, Middle and Lower zones of aquifers. Aquifers could be water table or semi confined with variable permeability laterally. The upper zone of aquifer is about 105 m thick at Maiduguri for example. The Middle zone is separated from the Upper by about 150 m of intercalations of clays, silts and sands. The Chad Formation tends to thicken towards Maiduguri axis and thins out towards Potiskum where the KareKare Formation is exposed. The topsoil was sandy with silt but in some areas clay was observed at the surface. The Kerri-Kerri Formation in the north-east is part of the Tertiary deposits. The Chad Formation overlies Kerri-Kerri Formation and is composed of basal sands and gravels with greenish clays above, the latter containing some minor bands of sands.

Sample collection and analytical methodology

A total of thirty Water samples were taken from hand-dug wells in Damaturu metropolitan. The samples location, samples code, longitude and latitude of each sampling point were taken with the aid of hand-held etrex 10 Garmin GPS equipment. The information concerning well data presented in Table 1. Water samples were collected by lowering the sampling bottle at depth of about 10cm below the surface after being rinsed with the same collected water sample before the actual sample collection ([11] , [12]). After collection, each sampling bottle was covered tightly to avoid leakage ([13] and [14])

The Radon concentrations in these samples were measured with RAD-7 an electric radon detector connected to RAD-H_2O accessory [15]. Figure 2 shows the setup of RAD-7 detector schematic diagram of RAD-H_2O which was used for measuring radon in water.

The 250 mL sample bottle was connected to the RAD-7 and the internal air pump of the radon monitor was used to re-circulating a closed air-loop through the water sample, purging radon from the water into the air-loop. The air is re-circulated through the water continuously to extract the radon until RAD-H_20 system reaches a state of equilibrium within about 5 min, after which no more radon can be extracted from the water. After reaching equilibrium between water, air and radon progeny attached to the passivity implanted planar silicon detector, the radon activity concentration measured in the air loop was used for calculating the initial radon-in-water concentration of the respective sample. The RAD-7 allows determination of radon-in-water activity concentration by detecting the alpha decaying progeny Po-218 and Po-214 using passivity implanted planar silicon detector. The radon monitor (RAD-7) uses a high electric field above a silicon semiconductor detected at ground potential to attract the positively charged polonium daughters (Po-218 and Po-214) which are counted as a measure of radon-222 concentration in air. The pump runs for 5 min, aerating the sample and delivering the radon to the RAD-7. The system will wait a further 5min and then it starts counting. During the 5 min aeration, more than 95% f the available radon is removed from the water and the components automatically perform everything required to determine the radon concentration in the water. After 5 min it prints out a short-form report. Thus radon gas is collected through the energy specific windows which eliminate interference and maintain very low back-grounds and later counted for the radon concentration.

Radon-222 activities are then expressed with uncertainty down to under ± 5%. At the end of the run (30 min after the start), the RAD-7 prints out a summary, showing the average radon reading from the four cycles, counted a bar chart of the four readings and a cumulative spectrum. The RAD-H_20 enables the measurement of radon in water over a concentration range between 30 and 105pCi/L (pico Cure/Liter).

Sample analysis

The master instrument have been calibrated by way of inter- comparison with secondary standard radon chambers designed by the USEPA. The accuracy of the master instrument was estimated to be within 4%, based on inter-comparison results. The overall calibration accuracy of our RAD-7 was established to be better than 5%the RAD-H_20 closed loop aeration method was employed [16] to measure the radon activity concentration in water samples. The rad AQUA continuous water measurement accessory was used so as to measure radon activity concentration in water to extremely low concentration, a process which ensures that the air volume and water volume are constant and

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independent of the floe rate. The results of measurement are shown on the RAD-7 screen after 30 minutes with an accuracy and sensitivity that exceeds that of other existing devices [17].

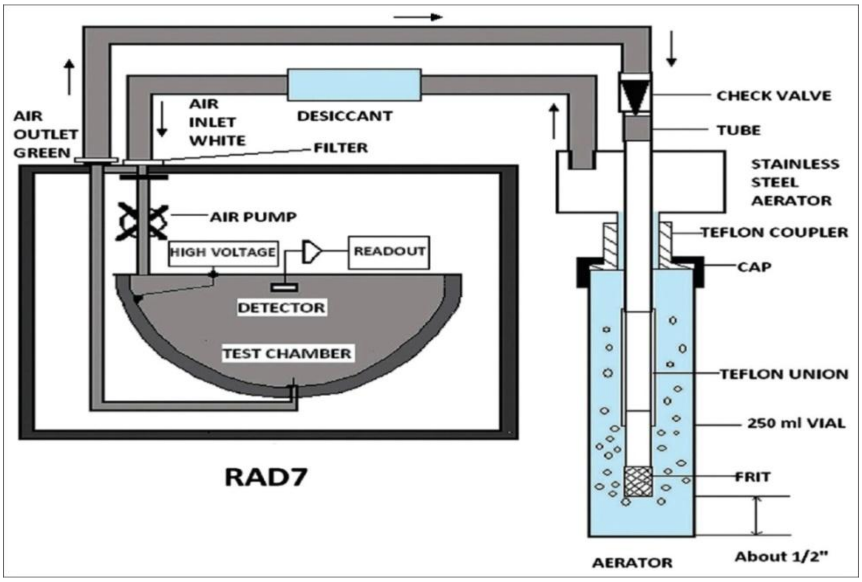

Fig. 2 Schematic representation of the RAD 7 instrument for measuring radon in water ([15]

Table 1 Water samples and Locations.

S/No.	Sample Code	Location	Longitude	latitude
1	W1	Al-Ansar Housing Estate	11.9522	11.7136
2	W2	Obasanjo Housing Estate	11.9639	11.7459
3	W3	3 Bed Room Gujba Road	11.9560	11.7164
4	W4	Jeru salaam ward	11.9634	11.7329
5	W5	Nasarawa	11.9565	11.7326
6	W6	Abbari	11.9579	11.7133
7	W7	Abba Ibrahim Housing Estate	11.9485	11.7277
8	W8	Sani Daura Housing Estate	11.9210	11.7231
9	W9	Sabon Fegi I	11.9756	11.7471
10	W10	Sabon Fegi II	11.9745	11.7452
11	W11	Don Etibet Housing Estate	11.9823	11.7434
12	W12	Gwange I	11.9666	11.7457
13	W13	Gwange II	11.9639	11.7459
14	W14	Pompomari I	11.9912	11.7513
15	W15	Pompamari II	11.9743	11.7500
16	W16	Hausari	11.8432	11.6745
17	W17	Bindigari	11.8274	11.6518
18	W18	Pawari	11.8184	11.6346
19	W19	Nayinawa	11.7891	11.6212
20	W20	Ali Marami Housing Estate	11.6742	11.5424
21	W21	Red Bricks Housing Estate	11.8652	11.6323
22	W22	Ajari	11.9712	11.7452
23	W23	Zanna Zakariya Housing Estate	10.9855	10.7378
24	W24	Federal Poly	11.9829	11.7416
25	W25	Bra-Bra Housing Estate	11.8925	11.6928
26	W26	Buhari Estate	11.8912	11.6901

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27	W27	Shettimari	11.7812	11.5782
28	W28	Dabo Aliyu Housing Estate	11.9914	11.7567
29	W29	Yobe State University	11.9526	11.6836
30	W30	Waziri Ibrahim Housing Estate	11.9881	11.7454

Estimation of Annual Effective Dose due to inhalation of Rn-222 from water

When radon is dissolved in groundwater, it can cause radiation exposure by consumption of drinking water and inhalation of radon emitted into the atmosphere when water is utilized [2]. Humans' radiological threats from consuming and inhaling dissolved radon in utility water were evaluated in terms of effective radiation dose received by the general public as a result of frequent groundwater use. The annual effective dose for inhalation and ingestion were determined using the formulas I equations (1-5) below respectively.

$$D_{inh}(\mu Sv) = CR_{nw} \times R_{aw} \times F \times O \times DCF$$
…………………………………..(1)

Where D_{inh} is inhalation effective dose, CR_{nw} radon concentration in water BqL^{-1}, R_{aw} is ratio radon in air to radon in water (10^{-4}), F; the equilibrium factor between radon and its progenies (0,4), O: average indoor occupancy time per individual (7000h) and DCF: dose conversation factor for radon exposure ($9X(10^{-6})$ $SvBq^{-1}h^{-1}m^{3}$ [2].

$$D_{ing}(\mu Sv) = CR_{nw} \times C_w \times EDC$$
…………………………………….(2)

D_{ing} : the effective dose for ingestion, C_w : the weight calculated for water consumption ($730Ly^{-1}$),and EDC: the effective dose coefficient for ingestion ($3.5X(10^{-6})$ $SvBq^{-1}h^{-1}m^{3}$ [2].

Annual committed effective dose to different age groups

To determine the annual committed effective dose as a result of ingestion and inhalation for different age group the equation by [18] is used

$$E = K \times G \times C \times T \times 1000$$
………………………………………………………
……...(3)

Where 1000 is the conversion factor from Sv to mSv, C is the concentration of radon; T is the period per year 365d/y. for the computation of E_{ing} (mSv/y) for infants, children and adults water consumption rates of 2L per day [18] is used. The respective radon values used are 18nSv/Bq, 26nSv/Bq and 35nSv/Bq for adult, children and infant.

Contribution of radon in different sources of water to indoor radiation

The contribution of radon in different sources of water to indoor radon was calculated using the equation:

$$X_{Rn} = C_{Rn} \times W \times \frac{\omega}{v \times \lambda_c}$$
……………………………………….(4)

Where X_{Rn} is the fractional contribution of waterborne radon to radon in indoor air, C_{Rn} is the radon concentration in water, W is the water consumption rate per person ($0.01m^{3}h^{-1}$), ω (0.5) is the coefficient to indoor air, v is the bulk volume of indoor air per person taken to be $20m^{3}$, λ_c ($0.7h^{-1}$) is the air exchange rate [19]

Excess lifetime cancer risk

The probability of cancer incidence was evaluated in order to assess any possible potential carcinogenic effects to human population for a specific lifetime of exposure to waterborne radon. Excess lifetime cancer risk, which shows the extra risk of occurrence of cancer due to exposure to waterborne radon in the community, was computed using the equation below:

$$ELCR = WBD \times RF \times DL$$
………………………………………………………
…………...(5)

Where WBD is the whole body dose in μSvy^{-1}, RF is the risk factor taken to be $0.05Sv^{-1}$ for stochastic effects and DL is the lifetime duration of 70years [20]

III. RESULTS AND DISCUSSION

The results of radon activity concentration (^{222}Rn) was found to be at its highest level in location W22 (Ajari) and the lowest concentration was found in water sample collected from location W13 (Gwange II). The radon (Rn-222) concentration in the water samples varied from 0.35 to 3.08Bq/L with a mean

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value of 1.23±0.09Bq/L against the global average of 11Bq/L. As shown in table 2.

Inhalation of radon from water varied from 1.03 to 8.57μSv/y with a mean value 1.26±0.28μSv/y respectively, the people leaving in location w21 (Red bricks) inhale more radon than people leaving in location w16 (Hausari). The results indicate that Red bricks and Hausari recorded the highest and lowest radon concentrations respectively. Red bricks having the highest mean also Hausari recorded the lowest deviation. Arithmetic mean and standard deviation of 8.57μSv/y was obtained for the study area. The total annual effective doses are found to be less than the safe limit of 100μ/Sv per y recommended by WHO and EU, hence it can be inferred that there is no significant health hazard due to groundwater radon concentration in the study area.

For ingestion of radon in water the AED varied from 1.14 to 7.86μSv/y with a mean value of 3.11±0.34μSv/y. The people leaving in location w22 (Ajari) ingest more radon than people leaving in location w13 (Gwange II). The total annual effective doses are found to be less than the safe limit of 100 μ/Sv per year, recommended by WHO and EU hence it can be inferred that there is no significant health hazard due to groundwater radon concentration

Table 2: The activity concentration of (^{222}Rn) in ($Bq.m^{-3}$) of drinking water sample in Damaturu metropolitan

Sample code	Radon conc. (Bq/l).	Ingestion (μSv/y)	Inhalation (μSv/y)
WI	0.99±0.07	2.53±0.18	1.25±0.88
W2	1.11±0.07	2.83±0.17	1.40±0.88
W3	1.41±0.08	3.60±0.20	1.78±0.19
W4	0.67±0.02	1.72±0.05	8.45±0.25
W5	0.35±0.09	1.71±0.76	4.41±0.38
W6	1.09±0.11	2.78±0.28	1.37±0.11
W7	2.09±0.08	5.33±0.24	2.63±0.19
W8	0.90±0.04	2.29±0.12	2.83±0.54
W9	0.60±0.03	1.53±0.76	7.56±0.38
W10	1.34±0.05	3.42±0.12	1.69±0.63
W11	0.80±0.13	2.04±0.32	1.09±0.16
W12	1.61±0.01	4.11±0.25	2.03±0.12
W13	0.56±0.03	1.43±0.76	7.06±0.38
W14	1.76±0.03	4.49±0.76	2.22±0.38
W15	2.09±0.07	5.33±0.17	2.63±0.88
W16	0.82±0.08	2.09±0.24	1.03±0.19
W17	0.97±0.34	2.47±0.86	1.22±0.42
W18	1.67±0.06	4.26±0.15	2.10±0.75
W19	1.09±0.09	2.78±0.29	1.37±0.13
W20	2.08±0.06	4.55±0.15	2.62±0.75
W21	0.68±0.07	1.73±0.17	8.57±0.88
W22	3.08±0.12	7.86±0.36	3.88±0.15
W23	1.34±0.08	3.42±0.24	1.69±0.19
W24	0.89±0.08	2.18±0.24	1.12±0.19
W25	2.09±0.03	5.33±0.76	2.63±0.38
W26	0.54±0.09	1.37±0.29	6.81±0.13
W27	2.10±0.13	5.36±0.32	2.64±0.16
W28	0.54±0.06	1.37±0.15	6.81±0.75
W29	0.45±0.02	1.14±0.51	5.67±0.25
W30	1.07±0.05	2.73±0.12	1.34±0.63
Mean	1.23±0.09	3.11±0.34	1.26±0.28
Min	0.35±0.09	1.14±0.51	1.03±0.19
Max	3.08±0.12	7.86±0.36	8.57±0.88

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Annual effective Dose (AED)

Results of the average radon of concentration in drinking water in Damaturu metropolitan were smaller than the accordable limit as reported in WHO [21]. The allowed maximum concentrations level for ^{222}Rn in water is 500 Bq.m^{-3}. The reason for variation in radon concentration could be a function of geological structure of the area, depth of the water source and also differences in the climate.as shown in table 3. Others have reported that the geological structure of an area is a predominant factor for high radon concentration and climate is also an important factor [22]

The total AED due to ingestion and inhalation of radon in water ranged from 1.10 to 5.87µSv/y with a mean value of 1.14±0.38 µSv/y. Showing the highest value of the annual effective dose in sample W22 (Ajari) was 5.87 µSv.y^{-1}, but the less value of the annual effective dose in sample W13 (Gwange II) was 1.10 µSv.y^{-1}. All results of the annual dose effective for ^{222}Rn of ground water in Damaturu were smaller than the normal limits of world 11 msv.y^{-1} [2]. as shown in figure 4.4.

Table 3: Result of Total Annual Effective Dose (Ingestion, Inhalation) of Radon -water samples

No	Name of location	AED (µsv/y-1)
1	Al-Ansar Housing	1.89±0.53
2	Obasanjo Estate	2.11±0.53
3	3 bedroom Gujba road	2.69±0.19
4	Jerusalem	5.08±0.15
5	Nasarawa	3.06±0.57
6	Abbari	2.08±0.21
7	Abba Ibrahim	3.98±0.22
8	Sani Daura	2.56±0.33
9	Sabon Fegi I	4.55±0.57
10	Sabon Fegi II	2.56±0.38
11	Don Etabet	1.57±0.24
12	Gwange I	3.07±0.19
13	Gwange II	1.10±0.57
14	Pompommari I	3.36±0.57
15	Pompommari II	3.98±0.53
16	Hausari	3.12±0.22
17	Bindigari	1.85±064
18	Pawari	3.18±0.45
19	Nayi Nawa	2.08±0.21
20	Ali marami	3.59±0.45
21	Red Bridcs	5.15±1.05
22	Ajari	5.87±0.51
23	Zanna Zakariya	2.56±0.22
24	Federal Poly	1.65±0.22
25	Bra-Bra estate	3.98±0.57
26	Buhari Estate	4.09±0.21
27	Shettimari	4.00±0.24
28	Dabo Aliyu	4.09±0.45
29	Yobe State University	3.41±0.38
30	Waziri Ibrahim	2.04±0.38

Comparison of Rn-222 in water with other studies

The results obtained in this project were compared with data from various studies in Ghana and other parts of the world. Most studies in Ghana have dealt much with borehole water and literature has shown that the surface water contains less radon dissolved in it (as most of it diffuses into the atmosphere) than the borehole water and this study found similar results with much lower mean value of 0.91Bq/L against the threshold of 11.1 Bq/L according to[23].

Table 4: Comparison with other studies of Radon concentration due to water ingestion

Country	Type of sample	Measurement techniques	Concentration (Bq/Rn-222	References
Nigeria	Groundwater	RAD7 Radon monitor	5.87	Present study
Ghana	Borehole water	HPGe	8.10	[24]
India	Tap water	RAD7 Radon monitor	4.7	[25]
Iraq	Tap water	Alpha Track detector	4.69	[26]
Global	Surface water	-	11.1	[27]; [28]

IV. CONCLUSION

The purpose of the project work was to determine levels of ^{222}Rn, ^{220}Rn plus ^{226}Ra, ^{232}Th and ^{40}K in water at Damaturu metropolitan and assess hazards posed by these natural radionuclide's to the public. The exposure pathways were outlined for the study area starting with, the internal exposure from drinking water containing natural radioactivity, to the inhalation of radon gas originating from water. Finally inhalation of radon gas originating from water. The communities covered during this work include Al Ansar housing, Obasanjo, nasarawa, Ajari, Gwange I & II, Waziri Ibrahim to mention just a few.

Radon, Thoron and other natural radionuclides assessment in water samples were measured by RAD7 Radon monitor. It has been observed that the Rn-222 concentration in the surface water samples is much lower than the international agreed value of 11.1Bq/L [27].The total annual effective dose for Rn-222 in water at the study area is 5.97 µSv/y which is very low compared to the world agreed value of 100 µSv/y according to [26]. One of the explanations for this is that most radon in the surface water diffuses into the atmosphere.

People at Damaturu use the surface water for drinking, washing clothing, cooking and other domestic purposes, so with these findings it can be concluded that the communities surrounding the area are not being exposed to significant levels of NORMs. This means they can freely use the water with very minimal radiological hazards, but pollutants like metals, organo-chlorine pesticide residues, polycyclic aromatic hydrocarbons etc. need to be assessed for drinking water quality purposes.

The average absorbed dose rate and the AED due to Ra-226, Th-232 and K-40 are less than the world values. In terms of soil gas radon and thoron they lie within the acceptable levels.

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