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Evaluation of Annual Effective Dose of Radon-222 Concentrations in Ground Water from Kotorkoshi and Its Rocky Environs, Zamfara State, Nigeria

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ABSTRACT

Radon-222 Concentration of groundwater varies with the geological formation of a place or region. However, the United States Environmental Protection Agency (USEPA) stipulated a limit of 11.1 BqL^{-1} for the Radon level in water. In this study, Radon activity concentrations were measured in thirty (30) samples of groundwater sources collected from three (3) rocky communities, comprising of; kotorkoshi, Kura and Sankalawa respectively, using a liquid Scintillation Analyzer. Result shows that the Radon concentrations of these region varies from 9.84 to 23.55 BqL^{-1} in well samples and 10.18 to 35.59 BqL^{-1} in borehole samples, with a mean value of 20.64 BqL^{-1} . These concentrations are higher than the maximum safety limit, above which remedial action is required. The annual effective doses due to ingestion and inhalation of the Radon were evaluated. Consequently, most of these samples had annual effective dose that are higher than the maximum permissible limit of 0.2 mSv^{-1} , if consumed by children, and 0.1 mSv^{-1} , by adults. Since granite is the major rock found in these areas, it is assumed that the geological structures of these environs, predominantly contributes to the Radon activity concentrations. However, the total annual effective doses from the entire location of the studied areas were above the safety limits, as recommended by World Health Organization (WHO) and European Union (EU) Council.

Keywords: Ground water, Liquid Scintillation Analyzer, Annual Effective Dose, Radon-222, Rocky Environs

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INTRODUCTION

Water is a liquid compound of oxygen and hydrogen found on the earth surface and underground, and could be polluted via harmful substances. However, it is of great important to know how safe groundwater is, from the radiological impact which could be highly contaminated with, most especially in the areas embedded with rocks and deposit of solid minerals. Contaminant such as Radon significantly pollutes the ground water sources (boreholes and wells), posing a devastating health effect (El-Taher, 2012). Radon-222, a natural product of ^{238}U , ^{235}U , and ^{232}Th , decays with the

Half-life of 3.824 days. Other Radon isotopes, ^{224}Rn and ^{219}Rn exist with half-lives of 55.6 and 4.0 seconds respectively are also produced, from the alpha decays of ^{224}Ra and ^{223}Ra , emanating from ^{232}Th and ^{235}U . However, ^{222}Rn which has the highest half-life is of great concern as the others are very short lived. Since, uranium is essentially ubiquitous in the earth crust; ^{226}Ra and ^{222}Rn are found in most rocks, soil, and even the water bodies (Karina et al., 2011; Garba et al., 2012). Aside cigarette smoking, Radon is also seen as the second most frequent cause of lung cancer in the United

States, resulting to 21,000 deaths per annum. However, findings have also revealed that, factors such as geological formation of the earth, geochemical properties of parent radionuclide, hydrological conditions and abundance of parent radionuclide amounts for potential parameters contributing to ^{222}Rn concentration in ground water (Bello et al., 2019; Akinagbe et al., 2018; Duggal et al., 2013).

Similarly, when Radon decays into air, it forms a number of short-lived radioactive decay products (Radon progeny), which includes polonium-218, polonium-214, polonium-210, bismuth-214, and bismuth-21, with half lives of 3.05 min, 1.5×10^{-4} , 190-day, 20 min, and 5 days respectively (Dowdall et al., 2013; Aruwa et al., 2017). Similarly, it has also been established that, about 50% of the annual effective radiation dose received by human is related to the Radon and its progeny. Epidemiological studies have shown a clear link between a high concentration of Radon and incidence of lung cancer. However, Radon concentration of water should be minimal and not to exceed the maximum contamination level of 11.1Bq/L (USEPA, 1999). Previously, studies conducted on the annual effective dose of Radon concentrations in ground water from Ijero-Ekiti (Akinagbe et al., 2018); Bagwai - Shanono (Bello et al., 2019), and Idah (Aruwa et al., 2017), respectively among others, have shown that most of the ground water samples in these region has Radon activities that is higher than the recommended value of the United State Environmental Protection Agency, and World Health Organization (WHO, 2004; USEPA, 1999). However, it is important, due to the formation of granitic rocks, spreading across kotorkoshi and its environs to evaluate the annual effective dose of Radon ingestion in ground water and the indoor inhalation dose. Evaluation of Radon concentration in these communities is of top-notch necessity, to knowing the safety level of the inhabitant populace.

MATERIALS AND METHOD

Location of the study area

Kotorkoshi, Kura and Sankalawa towns are all located in the rocky enclave of Bungudu Local Government Area of Zamfara State, Nigerian. These communities lie between latitude $12^{\circ}8'26''$ to $12^{\circ}9'21''\text{N}$ and longitude $6^{\circ}47'11''$ to $6^{\circ}49'19''\text{E}$, with temperatures ranging from 59°F to 101°F throughout the year. These environs rely only on ground water source, for the purpose of drinking and domestic activities, for the population of 16,173 as at the 2006 census (National Population Commission 2006). This area is part of the Precambrian basement complex, and is predominantly agrarian, with residents engaged in farming and related activities. Prominent geographical feature is the kotorkoshi Rock, a massive granitic formation rising about 350 meters above sea level and covering approximately one square mile, spreading towards Kura, Sankalawa and beyond.

Sample collection

In this research, the stratified random sampling technique was adopted for the sample collection thereby attributing equal proportion of selection to all the location in reference to guidelines (Suomela, 1993). The sampling location was designed into three strata, in consideration of proximity of the members of public to the rock, those closer and those that are few meters – a way. However, a total of Thirty (30) samples of ground water were selected, comprising of seventeen (16) from hand pump boreholes, which were directly drawn from the pump after allowing the water to initially run for about fifteen (15) minutes. Similarly, fourteen (14) samples of hand dug-wells were also drawn, using a bailer. However, both of these samples were collected into a plastic sample container. Prior to sampling, sample containers were already been washed with distilled water and later rinsed with hydrochloride acid (HCL) to prevent any form of contaminant. Subsequently, samples were filled-up to beam of the containers and tightly covered to avoid out gassing of Radon concentration. Immediately after the sampling, samples were numbered with respect to sampling points and the sample sources involved, and taking into accounts; are the time and date of collection respectively. Similarly, the GPS coordinates of the sampling points were also measured, and recorded. After sampling, samples were immediately transferred to the Centre for Energy Research and Training (CERT) Ahmadu Bello University, Zaria Nigeria, for preparation and analysis.

Sample preparation

Samples preparations were respectively carried out in accordance to the standard procedures as reported (Suomela, 1993). Ten ml each of the samples were carefully measured into to a liquid scintillation vial, which were containing ten ml of scintillation cocktail, using a disposable syringe to minimize out-gassing, Radon by aeration. However, the vial was tightly-covered and the mixtures were vigorously shaken, to enable the extraction of Radon from the water phase to organic scintillation solution, it is solubility in organic liquids. Subsequently, mixtures were allowed to settle for three hours plus, to enable growth of the short-lived decay products of Radon and attainment of secular equilibrium (Aruwa et al., 2017; Shimori et al., 2013; WHO, 2004).

Measurement of Radon concentration in water

The measurement standard procedure reported by (Dowdall et al., 2013) was employed in the analysis. However, the prepared samples were counted using liquid Scintillation Counter (Tri-Carb-LSA1000) located at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria. Prior to counting, the Liquid Scintillation counter was calibrated with IAEA standard solution ($^{226}\text{Radium}$). Subsequently, Sample analysis begins and the Radon activities were

Table 1: Radon specific activity (Bq/L) and the Annual Effective Dose (Svy⁻¹)

Latitude (°)	Longitude (°)	Sample Code	Sample Location	Radon Activity	Annual Effective Doses (μSvy^{-1})			AED _{Total} (μSvy^{-1})	
					Ing (A)	Ing (C)	Inh	Adult	Children
12.62	6.65	B01	Marerawa	31.45	229.5	344.4	79.254	308.84	423.63
12.67	7.12	W02	Yar-kure	20.18	147.3	220.9	50.854	198.17	271.82
12.95	6.54	W03	Limanchi	19.96	145.7	218.6	50.299	196.01	268.86
13.39	6.46	B04	Kagara	35.59	259.8	389.7	89.687	349.49	479.39
12.54	6.74	B05	Rusawa	29.39	214.6	321.8	74.063	288.61	395.88
12.81	6.95	B06	Nakoto Road	30.51	222.7	334.1	76.885	299.61	410.97
12.78	6.77	W07	Sabawa	18.42	134.5	201.7	46.418	180.88	248.12
12.94	6.55	B08	Barakallahu	29.79	217.5	326.2	75.071	292.54	401.27
12.79	7.00	B09	Nassarawa	30.81	224.9	337.4	77.641	302.55	415.01
12.91	6.97	W10	Kofar Bai	19.99	165.1	188.9	50.375	196.30	267.89
12.67	7.12	B11	Along Kura	30.59	223.3	334.9	77.087	300.39	412.05
12.95	6.54	W12	Crush- Site	23.55	171.9	343.8	59.346	231.26	317.22
13.39	6.46	W13	Barebari	22.92	167.3	334.6	57.758	225.07	308.73
12.54	6.74	B14	Dukkura	28.86	210.8	421.4	72.727	283.41	388.74
12.81	6.95	B15	School site	26.78	195.9	390.9	67.486	262.98	360.73
12.78	6.77	W16	Fegi-1	19.78	144.9	288.8	49.846	194.24	266.44
12.94	6.55	W17	Fegi-2	16.02	116.9	233.9	40.370	157.32	215.79
12.79	7.00	W18	Fegi-3	20.51	149.7	299.5	51.685	201.41	279.27
12.91	6.97	W19	Fegi-4	18.06	131.8	263.7	45.511	177.35	243.27
12.62	6.65	B20	Fegi- Mkt	28.79	210.7	420.3	72.551	282.72	387.80
12.62	6.65	B21	Sabon Gida	15.29	111.5	167.4	38.531	150.15	205.96
12.67	7.12	B22	Kulodo	13.04	095.2	142.8	32.861	128.05	175.65
12.95	6.54	B23	Market	19.71	143.9	215.8	49.669	193.53	265.49
13.39	6.46	W24	Gusau Road	09.84	071.8	107.8	24.797	096.83	132.54
12.54	6.74	W25	Check point	11.65	085.1	127.6	29.358	114.40	156.93
12.81	6.95	B26	Hospital	12.25	089.4	134.1	30.870	120.29	165.01
12.78	6.77	B27	Fugus Mosq.	10.18	074.3	111.5	25.654	099.97	137.12
12.94	6.55	B28	Fugus-FOS	10.61	077.5	116.2	26.737	104.19	142.92
12.79	7.00	W29	Sank-Mkt	11.56	084.4	126.6	29.131	113.52	155.71
12.91	6.97	W30	Kura Road	09.98	072.9	109.3	25.149	098.00	134.43

respectively counted for sixty (60) minutes. Since the counting was not done at the time of sample collection, Radon concentration of the samples must have reduced due to radioactive decay. Hence, the Radon activity concentrations were evaluated, by considering the counting parameters; such as sample the volume, total and background count rates, decay time (time between Sample collection and counting), and efficiency of detection, by substitution into equation (1) (Garba et al., 2012).

$$R_n(\text{Bq/L}) = \frac{100 \times (N_s - N_b) \exp \lambda t}{60 \times 5 \times 0.964} \quad (1)$$

Where:

R_n = Radon concentration as at the time of sample collection (Bq/L); N_s = sample total count rate (count min.⁻¹); N_b = Background count rate (count min.⁻¹); N = Net count rate (count min.⁻¹); t = Elapsed time between sample collection and counting (4320min; 3days); λ = ²²²Rn decay factor (1.26×10^{-4} min.⁻¹). Notes: 100 is the conversion factor of 10 ml to per liter; 60 is also a conversion factor from minute to seconds; 5 (500%) is number of emissions per disintegration of ²²²Rn (3α and 2β , assuming 100% detection efficiency for each); and 0.964 is the fraction of ²²²Rn in the cocktail contained in vials of the mixtures.

Estimation of annual effective doses

(a) Ingestion

The mean Annual Effective Dose due to the ingestion of Radon in drinking water was estimated using Eq. (2)

(Akinagbe et al., 2018).

$$\text{AED}_{\text{ing}} = C_{Rn} \times W_{CR} \times D_{\text{ing}} \quad (2)$$

Where, AED_{ing} = Annual Effective Dose from drinking water containing Radon (Svy⁻¹); C_{Rn} is the concentration of Radon in water; W_{CR} is values of consumption rate (Ly⁻¹) in accordance to "ICRP standard man" adopted, for adults and children as; 2.0, 1.5 liters per day (Equivalent to 730 and 547.5 Ly⁻¹) respectively; D_{ing} = Ingestion dose conversion factor of Rn-222 (SvBq⁻¹), for adults and children $D_{\text{ing}} = 10^{-8} \text{ nSvBq}^{-1}$, $2 \times 10^{-8} \text{ nSvBq}^{-1}$ respectively (Bello, 2019).

(b) Inhalation

The mean Annual Effective Dose due to the inhalation of Radon Radon-in-air to Radon in-water was estimated using Eq. (3)

$$\text{AED}_{\text{inh}} = C_{Rn} \times R_{AW} \times E_F \times O_F \times D_{\text{inh}} \quad (3)$$

Where C_{Rn} is the concentration of Radon in water, R_{AW} is the ratio of Radon-in-air to Radon in-water (10^{-4}), E_F is the equilibrium factor between Radon and its progeny for indoor environment (0.4), O_F is the average global indoor occupancy factor (7000hy⁻¹) and D_{inh} is the dose conversion factor for exposure to Radon in air ($9 \text{ nSv Bq}^{-1} \text{ h}^{-1} \text{ m}^{-3}$) (Umar et al., 2024).

RESULTS AND DISCUSSION

Table 1 presented the Radon specific activity concentrations (Bq/L) in ground water and the corresponding annual effective doses in borehole and

Table 2: Comparison of Radon-222 concentration with literature values

Water type	Radon (Bq/L)	Region, Country	References
Ground water	9.48- 35.59	Kotorkoshi-- rocky environs	This Work
Drinking Water	3.176 - 49.93	Shanono-Bagwai, Nigeria	(Bello et al., 2019)
Ground water	7.94 - 21.21	Idah, Kogi State, Nigeria	(Aruwa et al., 2017)
Ground water	0.77- 21.23	Zaria, Nigeria	(Garba et al., 2012)
Drinking water	1.20 - 9.88	Babylon, Iraq	(Sadiq and Jabbar, 2013)
Ground water	13.88- 28.67	Brazil	(Karina et al., 2011)
Ground water	0.17- 78.51	Ijero- Ekiti, Nigeria	(Akinngbe et al., 2018)
Ground water	0.90- 5.10	Punjab- India	(Duggal et al., 2013)
Drinking Water	6.93 – 22.74	Various Location- Sudan	(Elzain, 2014)
Ground water	0.187- 14.8	Mehriz Villages- Iran	(Mohammad, and Hasan, 2015)
Ground water	0.52-5.36	Lapai, North central, Nigeria	(Umar et al., 2024)
Ground water	21.59-27.93	Edu, North-central, Nigeria	(Ajibola et al., 2020)

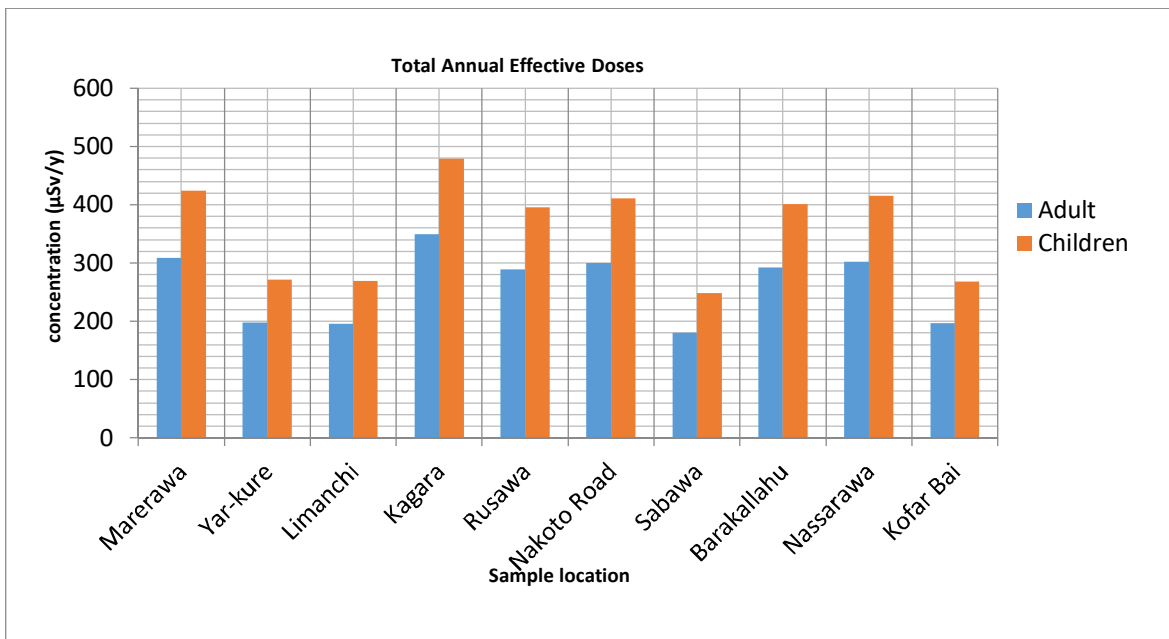


Figure 1: Annual Effective Doses of Radon-222 in kotorkoshi

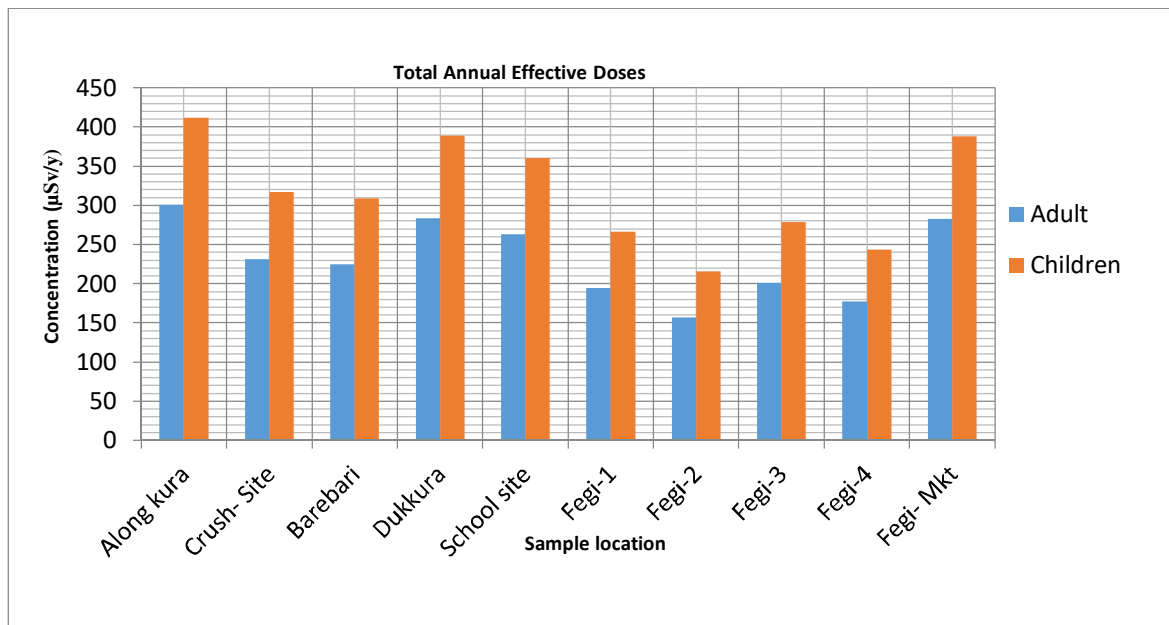


Figure 2: Annual Effective Doses of Radon-222 in Kura

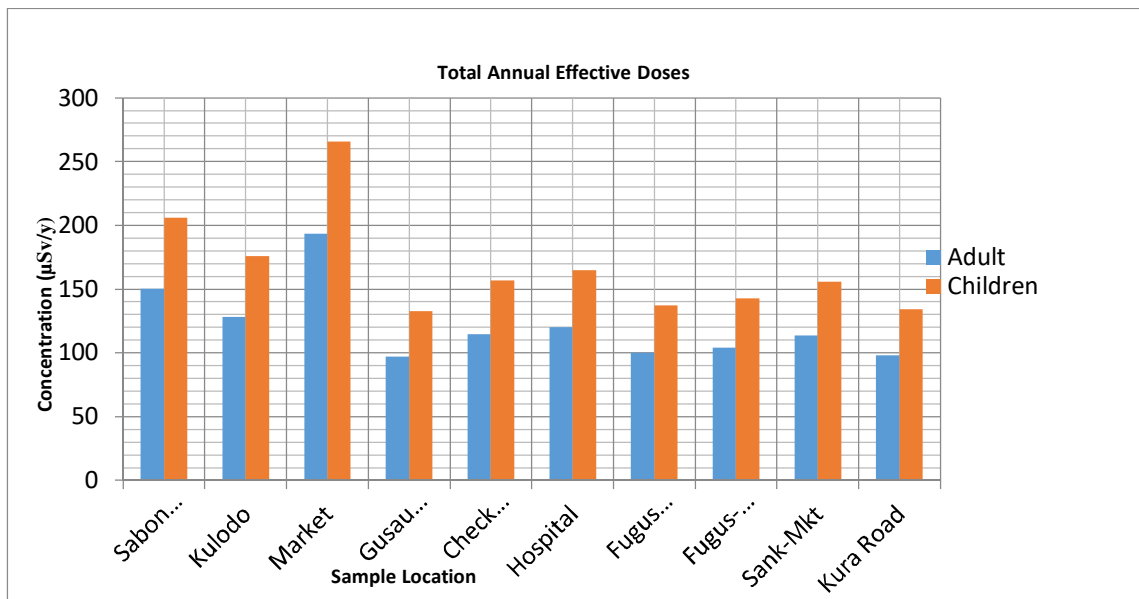


Figure 3: Annual Effective Doses of Radon-222 in Sankalawa

well water samples used for drinking and domestic activities from the researched areas. Result shows that the total arithmetic mean concentration of the sources was twice greater than the maximum permissible limits of 10 Bq/L and 11.1 Bq/L recommended by WHO and USEPA Respectively (Oni et al., 2014; USEPA, 1999). However, the arithmetic mean value in well and borehole samples were 17.311 and 23.978 Bq/L, with activity concentration, ranging from 9.84-23.55Bq/L and 10.18--35.59/L respectively. The highest activity concentration (35.59 Bq/L) was recorded in borehole sample from Kagara community of Kotorkoshi while the least value, 10.18Bq/L was also recorded in well sample from Kulodo community of Sankalawa axis. Irrespective of the sources, 26 (86.7%) out of 30 (100%) sample analyzed, had Radon concentration higher than the maximum permissible limit of 11.1 Bq/L and the WHO value of 10 Bq/L (Oni et al., 2014; USEPA, 1999). Generally, the Radon activity levels in ground water of these communities were higher than limit in 14 samples of the borehole water, and 12 samples of the well water. The highest activity observed from both sources might be due to the granitic rocks embedded in the studied areas. However, since the saturated zone of the earth crust has been reported to contain high amount of Radon. This implies that the depth of the source is also a predominant factor for a higher Radon concentration as observed in the borehole sources from previous studies (Shimori et al., 2013; Samaila et al., 2023). However, in table 2, the results of this present research are compared with those obtained from other regions. The values obtained are in agreement with the results from other countries.

The Activities of the Annual Effective Doses from the ingestion and inhalation of Radon in ground water sources consumed by both adults and children of

kotorkoshi and its neighboring environs were calculated using equations (2-3), and are presented in (Table 1) above. The minimum to maximum (Adults--children) values of the entire sample were evaluated from 134.5--259.8µSv/y to 201.7--389.7µSv/y in kotorkoshi samples; 116.9--223.3µSv/y to 233.9—421.4.9µSv/y in Kura samples, similarly 071.8—143.9µSv/y to 107.8—215.8µSv/y in Sankalawa samples, respectively. Similarly, the total Annual Effective means value, presented in figures (1-3) were also evaluated as 261.30-358.4µSv/y (0.261-0.358mSv/y) in kotorkoshi; 231.61µSv/y--317.7µSv/y (0.232—0.318mSv/y) in Kura and 121.88µSv/y-167.1µSv/y (0.121—0.167µSv/y) in Sankalawa samples respectively. Consequently, it was observed that most of the samples from both sources had annual effective doses higher than the maximum permissible limit of 0.2mSv/y when consumed by children and 0.1mSv/y by adults, respectively.

Conclusion

This work evaluates the Radon level and the annual effective doses in drinking water sources of Kotorkoshi and its Surrounding rocky Environs, located in Bungudu Local Government Area, Zamfara State, Nigeria in order to ascertain the radiological safety level. The average Radon activity concentration and the corresponding annual effective dose for the adults and children has shown that most the ground water samples, from this communities are not safe for drinking and domestic activities, except for few samples from Sankalawa communities that had values within the world Health Organization (WHO) and united state environmental Agency (USEPA) acceptable thresholds. This signifies that there is a need for immediate action, for Radon reduction, as mitigation is the only option reported to have eased the high Radon level in water (WHO, 2011;

USEPA, 2003). However, it is eminently important to also replicate this kind of researched across all the rocky zones of zamfara, since the state is blessed with solid mineral resources, there could be areas of high radiation areas, as this will help to identify the Radon risk level

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