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Thermal Treatment of Radon-222 Concentrations of Drinking Water in Zamfara State, Nigeria

Abdulazeez, N.*, Ogbanje, J. L., and Zakari, M. S.

Department of Science Laboratory Technology, Federal Polytechnic Kaura Namoda, Zamfara State, Nigeria.
Corresponding Author E-mail: madugunaj6@gmail.com

ABSTRACT

Excessive Radon (^{222}Rn) activity concentrations of drinking water cause illnesses of radiological concern that could be avoided. In this paper Radon Mitigation remedy were carried out by thermal treatment in thirty (30) samples of ground water collected from the rocky communities of Kotorkoshi, Kura and Sankalawa environs in Bungudu Local Government Area of Zamfara state, Nigeria. However, Liquid Scintillation counter was used for the measurement of the radon activities. Initially the radon activity concentrations were higher than the upper bound (11.1 Bq/L), to which remedial action is required, as recommended by United State Environmental Protection Agency (USEPA). However, the thermal treatment was initiated by heating-up the samples (200ml) each in closed a beaker until, a temperature of 100^0C boiling points were attained at time interval of thirty (30) minutes respectively, within a period of three (3) days. Similarly, radon activity concentrations obtained, varies from 9.38-19.73Bq/L (out of the initial concentrations of 18.42-35.59Bq/L) in kotorkoshi; 4.34-10.02Bq/L (out of the initial concentrations of 9.84-11.65Bq/L) in Sankalawa and 8.43-18.42 Bq/L (out of the initial concentrations of 16.02-30.59Bq/L) in Kura community. However, the Average Annual Effective Dose from the entire locations of the researched areas were found, within the limits of 0.1mSvy^{-1} and 0.2mSvy^{-1} for the both adults and children respectively, as recommended by World Health Organization (WHO) and European Union (EU) Council.

Keywords: *Thermal Treatment, Radon-222, Drinking water, Liquid Scintillation Counter, Concentrations*

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INTRODUCTION

Radon is a colorless, odorless, and tasteless radioactive element of the noble-gas family, occurring naturally as one of the decay products of the uranium-238 series. As the most concerned isotope, ^{222}Radon, exiting with the half-life of 3.82 days is a direct product of ^{226}Ra decaying alpha (Karina et al., 2011). Since its discovery radon could be released through rocks, soils, minerals, and sediments and may be dissolved in ground water. The radon concentration of groundwater sources mainly depends on the Radium content of the rock aquifer. However, radon concentration varies with respect to the geological formation of a region and meteorological factors such as atmospheric pressure, temperature, season of year, among others. Human are exposed to radon through ingestion and inhalation, parts of the mechanisms that transport the radon into our dwelling are the soil emanation and radon release from the water body (Duggal et al., 2013; Umar et al., 2024). However, the consumption of water with high level of radon gas is related to about 11% cancer of risk. Long-term studies performed in different countries over decades results in the explicit conclusion that exposure to radon and its progeny can cause chromosomal changes, irreversible damage to lung cells of the respiratory system and possible cancer. Radon surveillance has increasingly been carried out worldwide due to its hazardous effects on the human health. Exposure to excess concentrations of radon and its daughters for a long period could results to pathological issues such as the respiratory functional changes and the occurrence of lung cancer. High radon concentration in drinking water could also lead to a significant risk of stomach and gastrointestinal cancer (Samaila et al., 2023). Through ingestion, human beings are exposed to radon activity in drinking water. However, radon evaluation of drinking water is extremely important because of the recognized health risks (Garba et al., 2012). Since groundwater is the only source of drinking water for the entire population of kotorkoshi and its rocky environs, the aim of the study is to carry out the thermal treatment of radon mitigation in water used for drinking and to evaluate the annual effective doses due to ingestion for the adults and children. Mitigation of radon concentration in drinking water is of great important to public health safety, considering that about 50% of the effective annual radiation dose received by a human being is related to the radon and its progeny. However, since radon is soluble in water with about 510 $cm^{-3}kg^{-1}$ at 0^oC and gradually decreases at higher temperatures (Karina et al., 2011; Khattak et al., 2011). In this scenario, therefore the thermal treatment was considered as one of the available methods for radon mitigation in water. The method is simple, economical and easy to be practiced by the rural dwellers, such as the inhabitant of kotorkoshi and its rocky environs.

MATERIALS AND METHOD

Study area

The study area (Kotorkoshi and its rocky environs), is located in Bungudu Local Government Area, of Zamfara State, Nigeria and is part of the Nigerian Precambrian basement complex, lying between latitude 12°8'26" to 12°9'21"N and longitude 6°47'11" to 6°49'19"E, with temperatures condition ranging from 59°F to 101°F throughout the year. These communities are predominantly agrarian, with residents engaged in farming and related activities. One of the prominent geographical features of this area is the Rock, a massive granitic formation rising about 350 meters above sea level and covering approximately one square mile. The climate here is characterized by a tropical savanna climate with distinct wet and dry seasons. The wet season is mostly cloudy and oppressive; while the dry season is generally clear (Figure 1).

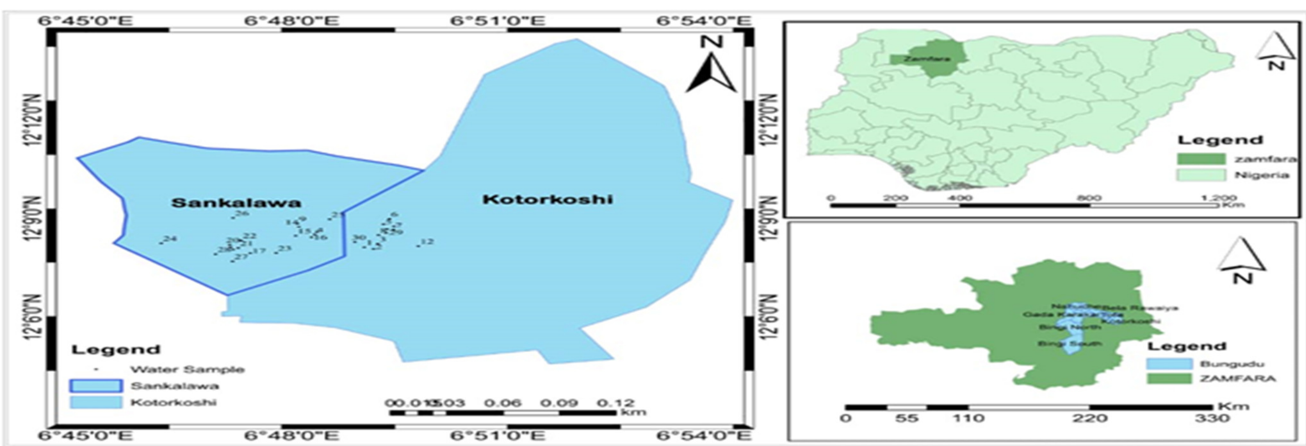

Figure 1: Map of the study areas

Sample collection

Thirty (30) samples of ground water were randomly selected from three strata of the researched areas, comprising of sixteen (16) from hand pump boreholes, which were directly drawn from the pump after allowing the water to initially run for about fifteen (15) minutes, and fourteen (14) samples of hand dung-wells were equally drawn, using a bailer. Both of these samples were collected into a plastic sample container. Prior to sampling, sample containers were washed with distilled water and later rinsed with hydrochloride acid (HCL) to prevent any form of contamination. These samples were collected in the month of August, at the mid-period of raining season and ensured that the container were filled-up and tightly covered to avoid out gassing of radon concentration. However, samples were uniquely numbered with sampling points and sample source types, noting the time and date of collection respectively. Similarly the GPS coordinates of the sampled points were equally traced, and recorded. In order to achieve accuracy, samples were immediately transferred to the laboratory and analyzed within three (3) days to ensure that sample composition not altered.

Sample preparation

The sample preparation was initiated by heating-up about

25ml, each of the samples in a closed beaker and allowed to attain a temperature of 100^0C. However heated samples were allowed to cool down before fetching. Prior to heating the samples, beakers were pre-washed with distilled water to avoid any form of contamination. Subsequently sample preparation proceeded in accordance with the standard procedures reported by Suomela, (1993). Ten ml each of the heated samples were carefully fetched and transferred to liquid scintillation vials, which were already containing ten ml each of liquid scintillation cocktail, using a disposable hypodermic syringe to minimize out-gassing the sample through aeration. Then, the vials were cover-tight and the mixtures vigorously shaken, for about 5 minutes to allow the extraction of radon-222 from water phase to the organic scintillation solution, since it is soluble in nature. Finally, prepared samples were kept in a safe place for about three hours, to allow for in-growth of the short-lived decay products of radon-222 and attainment of secular equilibrium (Bello et al., 2019; Garba et al., 2012).

Determination of Radon concentrations in water

The procedure reported by (Garba, 2012) was adopted for the measurement of ^{222}Rn concentrations in water. The prepared samples were analyzed with a liquid scintillation analyzer, located at the centre for energy research and training (CERT) Ahmadu University, Zaria Nigeria. However, prepared samples were kept in a safe place for about three hours after preparation in an attempt to secure equilibrium between in-growth of the short-lived decay products of radon-222 and attainment of secular equilibrium. Subsequently radon activities were respectively counted for sixty (60) minutes. Prior to counting the detector was, firstly calibrated with IAEA standard solution (^{226}Radium). Since the counting was not done at the time of sample collection, the radon concentration of the samples must have reduced, due to radioactive decay phenomenon (Bello et al., 2019).

Evaluation of Radon concentration in water

The radon concentrations (Bq/L) in drinking water were carefully evaluated, considering the counting parameters; sample volume, total and the background count rates, decay time (time between sample collection and counting), efficiency of detection and substituted into equation (1) and hence, Radon -222 concentrations in each of the samples is determined (Suomela, 1993; WHO, 2004).

$$\text{Rn(Bq/L)} = \frac{100 \times (N_S - N_B) exp\lambda t}{60 \times 5 \times 0.964} \quad (1)$$

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** = ^{222}Rn decay factor (1.26 x 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 ^{222}Rn (3α and 2β, assuming 100% detection efficiency for each); and 0.964 is the fraction of ^{222}Rn in the cocktail contained in vials of the mixtures (Bello et al., 2019).

Estimation of the annual effective dose

The average Annual Effective Dose due to the ingestion of radon in drinking water was estimated using the Eq. (2) (USEPA, 1999, Akinnagbe et al., 2018)

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

Where, AED_{ing} =Annual Effective Dose from drinking water containing radon (Svy^{-1}); C_{Rn} is the concentration of radon in drinking 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_{ing}= 10^{-8}nSvBq^{-1}, 2×10^{-8} nSvBq^{-1} respectively [Tabar and Yakut, 2014, UNSCEAR (1993; ICRP , 1997; ICRP, 2005; Desideri et al., 2007).

RESULTS AND DISCUSSION

Drinking water with excessive radon activity concentration needs to be mitigated before been consumed (WHO, 2011; Desideri et al., 2007). In this work, thermal treatment of Radon concentration of drinking water was carried out in thirty samples of ground water from kotorkoshi and its surrounding rocky environs, which were initially measured as higher than 10.0 Bq/L and 11.1 Bq/L limits stipulated by the World Health Organization (WHO, 2011) and United State Environmental protection Agency (USEPA) respectively, above which remedial action is required (ICRP, 1997, ICRP, 2005; USEPA, 2003). However, this treatment has significantly reduced the activities to a bearable minimal level as represented in (Figures 2-4), with the overall activity concentration ranging from 4.34-19.73Bq/l in both Samples, when compared with the initial activity, which ranges from 9.84--35.59 Bq/L. However, samples from kotorkoshi had the highest radon activity concentration of 9.38-19.73Bq/L (out of the initial values of 18.42-35.59Bq/L), this may due to proximity from the rocky zone. Sankalawa communities recorded the lowest activity concentrations, ranging from 4.34-10.02Bq/L (out of the initial value of 9.84-19.71Bq/L). Similarly, Kura communities which maintain the mid-point also have radon activity concentration ranging from 8.43-18.42 Bq/L (out of the initial values of 16.02-30.59Bq/L). These values have been reduced by 50 % in well samples and 45% in borehole samples. However, it was observed that none of these samples had radon concentration that is up to 20Bq/L after mitigation. Irrespective of the sources, 16

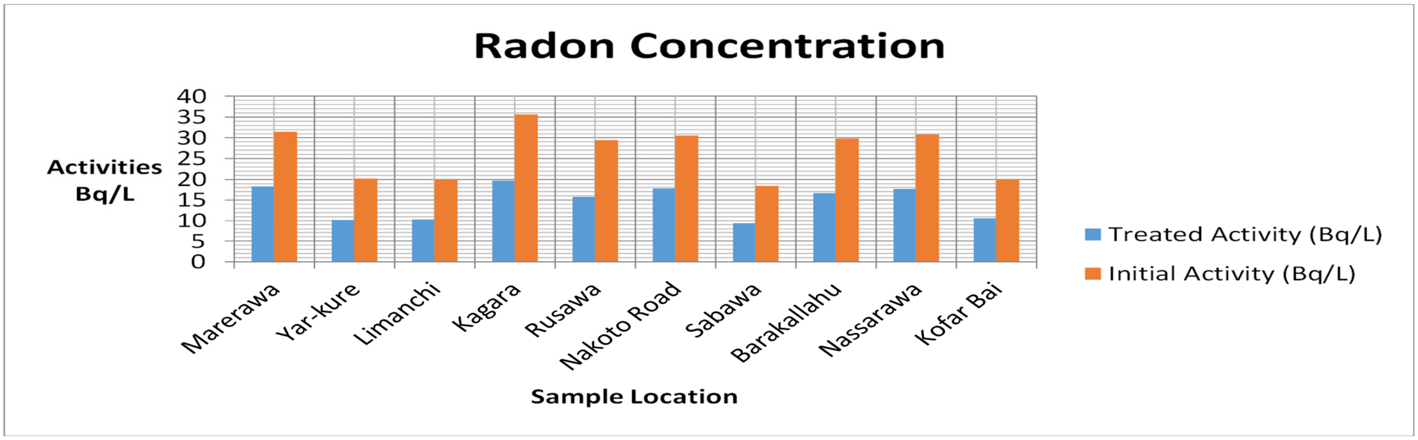

Figure 2: Comparison of radon-222 distribution of ground water in kotorkoshi

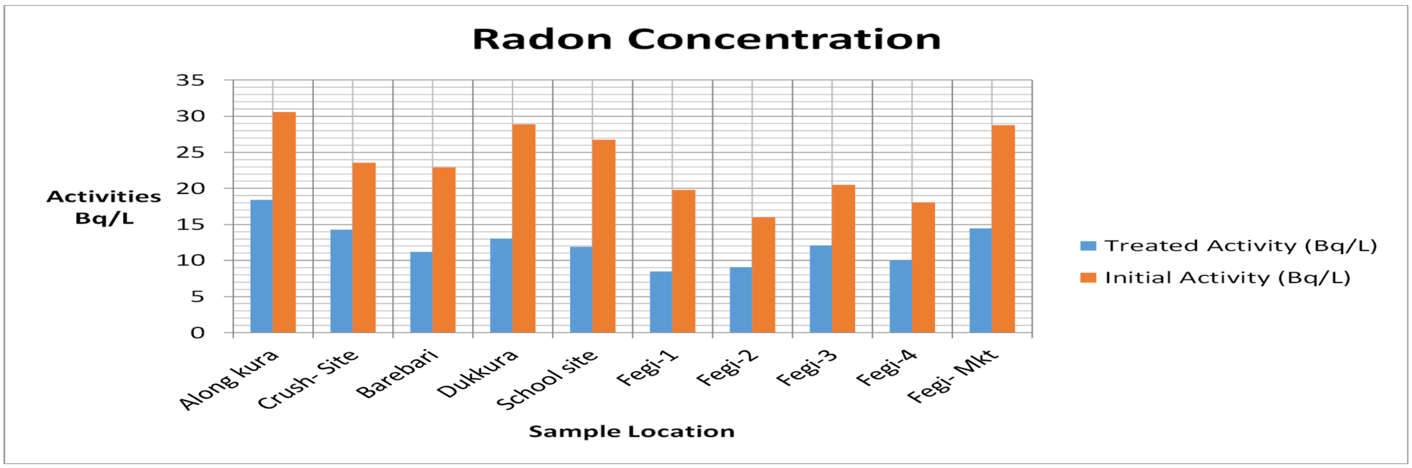

Figure 3: Comparison of radon-222 distribution of ground water in Kura.

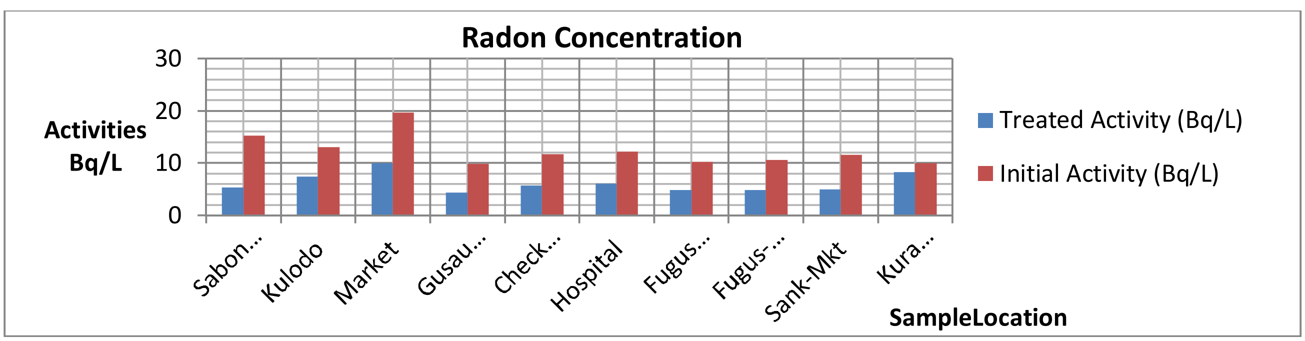

Figure 4: Comparison of radon-222 distribution of ground water in Sankalawa

(53.3%) out of the 30 samples analyzed for the thermal treatment had radon concentration that is far below the maximum permissible limit (11.1Bq/L) of acceptable threshold, meaning that the thermal treatment is also an effective method of mitigating radon in water (ICRP, 1997).

Annual effective dose of Radon in drinking water

The Annual Effective dose of Radon ingestion in drinking water of kotorkoshi, Kura and Sankalawa were calculated using equation (2) for the both adults and children; after undergoing the thermal treatment and the results were presented in tables (1-3) above. The total annual presented in (Tables 1-3) above. The total annual effective dose for the ingestion varies from the adults to the children by; 0.0685–0.1027 mSv/y to 0.1440--0.2160mSv/y in kotorkoshi samples; 0.0615µSv/y--0.0923 to 0.1345--0.2017 in Kura samples and 0.0317--0.0475mSv/y to 0.073--0.1097mSv/y in Sankalawa samples respectively. However, irrespective of the source of drinking, the total annual effective dose from the entire

Table 1: AED of Radon due to ingestion in kotorkoshi Communities

Sample Type	Sample Identity	Sample location	AED (μSvy^{-1})	
			Ing (A)	**Ing (C)**
Borehole	K1	Marerawa	0.1339	0.2008
Well	K2	Yar kure	0.0749	0.1125
Well	K3	Limanchi	0.0759	0.1134
Borehole	K4	Kagara	0.1440	0.2160
Borehole	K5	Rusawa	0.1149	0.1724
Borehole	K6	Nakoto	0.1372	0.1948
Well	K7	Sabawa	0.0685	0.1027
Borehole	K8	Barakallahu	0.1213	0.1819
Borehole	K9	Nassarawa	0.1215	0.1932
Well	K10	Kofar Bai	0.1425	0.2137

Table 2: AED of Radon due to ingestion in Kura Communities

Sample Type	Sample Identity	Sample location	AED (μSvy^{-1})	
			Ing (A)	**ing (C)**
Borehole	R1	Along Kura	0.1345	0.2017
Well	R2	Crush- Site	0.1043	0.1565
Well	R3	Barebari	0.0813	0.1219
Borehole	R4	Dukkura	0.0953	0.1430
Borehole	R5	School site	0.0867	0.1301
Well	R6	Fege-1	0.0615	0.0923
Well	R7	Fege-2	0.0658	0.0988
Well	R8	Fege-3	0.0882	0.1323
Well	R9	Fege-4	0.0729	0.1094
Borehole	R10	Fege-Mkt	0.1055	0.1582

Table 3: AED due to ingestion of Radon in Sankalawa Communities

Sample Type	Sample identity	Sample location	AED ($mSvy^{-1}$)	
			Ing (A)	**Ing (C)**
Borehole	Sn	Sabon Gida	0.0388	0.0582
Borehole	Sn	Kulodo	0.0543	0.0816
Borehole	Sn	Sabo- Mkt	0.0731	0.1097
Well	Sn	Gus.-road	0.0317	0.0475
Well	Sn	Check-pt	0.0414	0.0621
Borehole	Sn	Hospital	0.0447	0.0670
Borehole	Sn	Fugus 1	0.0356	0.0534
Borehole	Sn	Fugus-2	0.0349	0.0523
Well	Sn	Sank-Mkt	0.0366	0.0549
Well	Sn	Kura Road	0.0600	0.0900

locations of the researched areas was found, below the limits of 0.1mSv y^{-1} and 0.2mSv y^{-1} if consumed by both adults and children, as recommended by the World Health Organization (WHO, 2014) and European Union (EU) Council (UNSCEAR, 1993). These values have also resonated with the thermal treatment model when compared with the initial concentrations.

Conclusion

This research assess the thermal treatment method, as a means of mitigating Radon Concentrations in Drinking water from Kotorkoshi and its rocky Environs of bungudu local government area in Zamfara State, Nigeria, in order to ensure the radiological safety of the inhabitant communities. However, this study has shown a remarkable trend of the radon reduction with activity concentrations ranging from 4.34 –19.73Bq/l in both analyses of the well and borehole samples, compared with the initial activity concentration, which previously ranges from 9.84-35.59Bq/L. However, the annual effective doses for the adults and children have also shown a similar trend of reduced activity. Similarly, the Data obtained from the studied areas have also shown that about 60% of the radon activity analyzed has concentration below the maximum permissible limit set by USEPA (USEPA, 2003, Akinnagbe, 2018). However, it will be of great benefit to investigation the radiological impact of soil, rocks and water across all the other rocky zones in zamfara state. This will help to identify and protecting the inhabitant populace from the risks associated with the ingestion and inhalation among others. There is also a need to conduct another method of mitigation in these researched areas, so as to compare the resolution and efficiency of the thermal treatment method.

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