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STATISTICAL ANALYSIS OF RADON CONCENTRATION IN BOREHOLE WATERS; CORRELATION TO GEOLOGICAL FORMATIONS KATSINA STATE, NORTH WESTERN NIGERIA

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ABSTRACT

Radon in borehole water serves as a source of natural radioactivity exposure through indoor air. Determination of naturally occurring radionuclides concentration in ground and surface waters is useful as a contribution to environmental health studies. In this research, statistical analysis of radon concentration in (borehole) water was conducted in Katsina state. The aim of this study is to analyse statistically the concentration of radon in borehole water in Katsina state and to establish a possible relationship between radon activity concentration in borehole water and underlying rock types. A total of 110 water samples were collected and analysed using Tri-carb 1000 Liquid Scintillation Counter (LSC) at the Centre for Energy Research and Training, Ahmadu Bello University. The overall average concentration of ^{222}Rn was found to be 69 ± 3 Bql^{-1} with geological formations, G8 and G7 having the highest and lowest concentrations with values of 75 ± 10 Bql^{-1} and 57 ± 4 Bql^{-1} respectively, which are higher than the world average values of 10 Bql^{-1} set by WHO and 11.1 Bql^{-1} set by USEPA. The results showed that radon concentrations are clearly correlated to rock types with acidic intrusive rocks associated with values which sedimentary rocks are associated with lower concentrations.

Keywords: Radon Concentration, Dose estimation, Geological Formations, Katsina State

INTRODUCTION

Factors that influence the release, uptake and distribution of natural radionuclides or even the source materials may change the concentration of radionuclides in groundwater over several orders of magnitude (Isam *et al.,* 2002). The radionuclide of concern in drinking water is, (^{222}Rn). Because (^{222}Rn) in groundwater constitutes a source of natural radioactivity to indoor air, therefore, assessment of radon concentration in ground and surface waters is of paramount importance as an input to environmental health research. Although radon is chemically unreactive, but under some rare conditions it can form compounds like clathrates and fluorides (Stein, 1983). It has the highest density and solubility of 9.37 g l^{-1} and 510 cm^{3} l^{-1} respectively amongst other inert gases (Bunger and Ruhle, 1994; Bello *et al*., 2020). Lithology of the water bearing layer mostly control the concentration of ^{222}Rn in groundwater (Banks *et al.,* 1998; Misdaq and Elharti 1997). High concentrations of ^{222}Rn could lead to detectable levels of ^{210}Pb and ^{210}Po, even though, sorption processes may affect the corresponding concentrations (Isam *et al.,* 2002). It has been reported that ^{222}Rn transfers from bedrock to groundwater through an alpha recoil process followed by diffusion (Bonotto and Andrews, 1999; Sun and Senkow, 1998). In dwellings, ^{222}Rn is usually transferred according to normal water usage, from water to air by out-gassing, especially if the water is agitated (Isam *et al.,* 2000). The ratio of the escaped ^{222}Rn from water to the indoor air to the ^{222}Rn concentration in water is of the order of 10^{-1} per Bql^{-1} (Hess *et al.,* 1985, 1990).

The primary routes of potential human exposure to radon are; inhalation and ingestion from dissolved radon in water. Although, high concentration of radon in groundwater may contribute to radon exposure through ingestion, the exposure risk through inhalation of radon released from water is usually more significant (Pourhabib *et al.,* 2021). When radon gas is inhaled, alpha particles emitted by its short-lived progenies (^{218}Po and ^{214}Pb) which are highly-ionized, can interact with the biological tissues in the lungs which could ultimately results in carcinogenic effects (Isam *et al.,* 2002). Exposure to radon at any level over a period of time can lead to its related health effect, it is therefore unlikely that there is a threshold concentration below which radon does not have the potential to cause lung cancer (ICRP, 2007).

Different studies associated with radon concentration in water have been conducted in different parts of Nigeria (Abba, *et al.,* 2020; Aruwa, *et al.,* 2017; Bello, *et al,* 2020; Garba *et al.,* 2011; Garba *et al.,* 2012; Joseph *et al.,* 2018). In Katsina State, however, more research associated with radon concentrations and its related health hazards in different water sources need to be conducted in order to fill in the existing data gap. This study been a pioneer, aimed to investigate and establish a possible statistical relationship between radon concentration in borehole water and the underlying geological formations. This result therefore, will serve as a baseline data for regulation and monitoring purposes.

METHODOLOGY

Study Area

The study area is one of the states of Nigeria. It is situated within latitudes 11° 8[1], 13° 22[1] North and longitudes 6° 52[1], 9° 20[1] East, with a total land mass of approximately 24,192 km^2. The study area has nine different geological formations

Table 1: List of Geological Formations and Soil Types with their Codes

Geologiocal Formations	Codes
Biotite Hornblende Granite	G1
Coarse Biotite Hornblende Granite	G2
Granite Gneiss	G3
Migmatite	G4
Porphyritic Gneiss	G5
Ryolite	G6
Sandstone	G7
Silicate Sheared Rock	G8

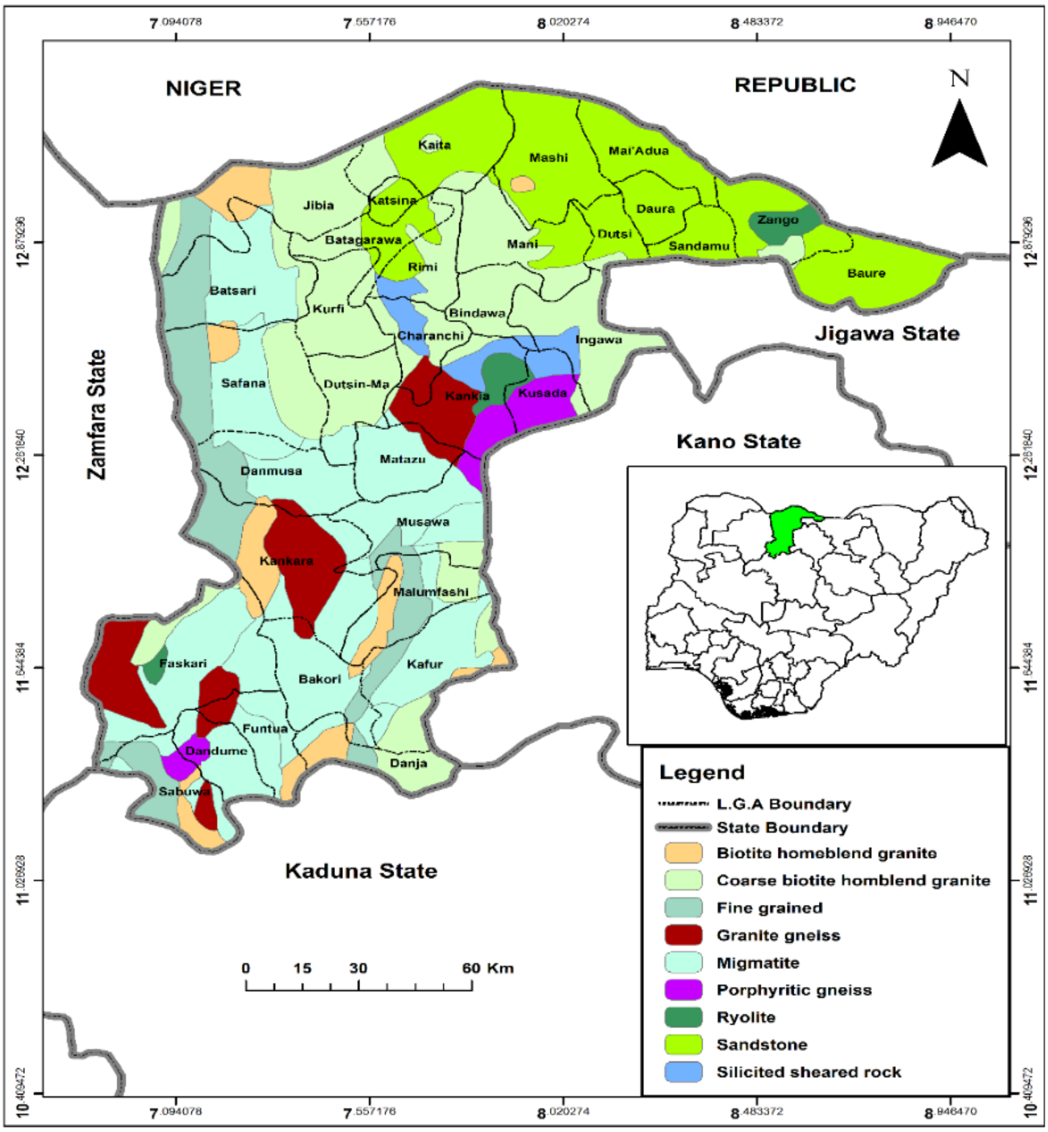

Figure 1**:** Geological map of the study area (Katsina State Ministry of Solid Minerals, 2010)

Samples Collection and Preparation

Borehole water samples were collected based on different geological formations of the state. A total of 110 water samples were collected which widely cover the study area using 2L sampling bottles. The samples were collected after the boreholes were allowed to run for about ten minutes before collection so as to have a more turbulent flow with uniform radon content. The bottles were filled and haematically sealed after concentrated HNO_3 acid was added to prevent absorption and precipitation of particulates on the container's wall. A handheld GPS device was also used to record the corresponding coordinates. The collected samples were then transported to laboratory for preparations.

About 10 ml from each sample bottle was drawn using syringe and transferred immediately into liquid scintillation vials, in which already there is 10 ml of scintillation cocktail. The vials were then shaken in order to extract ^{222}Radon from the water phase to the organic scintillate solution. The prepared samples were then kept for about 3hr to allow the ^{222}Rn and its short-lived decay products to attain radioactive equilibrium.

Table 2: Sampling Location Codes with their Corresponding Coordinates

S/N	Code	Rock Type	Coordinates (^{0})	
			Latitude	Longitude
1	G1	Biotite Homeblend Granite	7.44	11.61
2	G2	Coarse Biotite Homeblend Granite	7.47	12.74
3	G3	Granite Gneiss	7.53	12.03
4	G4	Migmatite	7.56	11.92
5	G5	Porphyritic Gneiss	7.61	11.99
6	G6	Ryolite	7.96	12.50
7	G7	Sandstone	7.81	12.90
8	G8	Silicified Sheared Rock	7.90	12.56

Samples Analysis

Determination of ^{222}Rn Concentrations

After preparations, liquid scintillation counter (LSC, Tri-Carb-LSA1000) was used to analyse the water samples. The counter is equipped with features will aid in achieving a detection limit of 0.407 Bq/l or less in 60 min (Abba, *et al.*, 2020; Bello, *et al.*, 2020). The background and sample count rates (counts min^{-1}) were recorded. ^{222}Rn and its short-lived daughters emit five radioactive particles (3 α and 2 β) per every disintegration of. Since equilibrium was established between ^{222}Rn and these decay daughters, all the five emissions were used in detection and quantifying ^{222}Rn in water. The ^{222}Rn concentration in a sample of water was determined using the Equation 1 (Garba *et al.*, 2012).

$$Rn = \frac{100\times(N_s - N_B)e^{\lambda t}}{60\times5\times0.964} \quad (1)$$

where Rn is ^{222}Rn concentration (Bql^{-1}), N_S is the sample total count rate (count min.$^{-1}$), N_B is the background count rate (count min^{-1}), t is the elapsed time between sample collection and counting (4320 min.), λ is ^{222}Rn decay factor (1.26 × 10^{-4} min.$^{-1}$), 100 is a conversion factor from per 10 ml to l^{-1}, 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.

RESULTS AND DISCUSSION

Mean Activity Concentration of ^{222}Rn

The study area has an overall average groundwater (borehole) ^{222}Rn concentration of 69 ± 3 Bql^{-1} with values ranging from 38 Bql^{-1} to 97 Bql^{-1}. This showed that the mean value obtained was about six times higher than the recommended limit of 11 Bql^{-1} set by USEPA (1999) and about ten times higher than the world average value of 10 Bql^{-1} reported by WHO.

Figure 2 below shows the distribution of radon concentration data. It can be noted that, the measured data fits in very well in the bell shape of the normal distribution curve which shows that the distribution of thedata is normal. and as such reliable conclusions can be made.

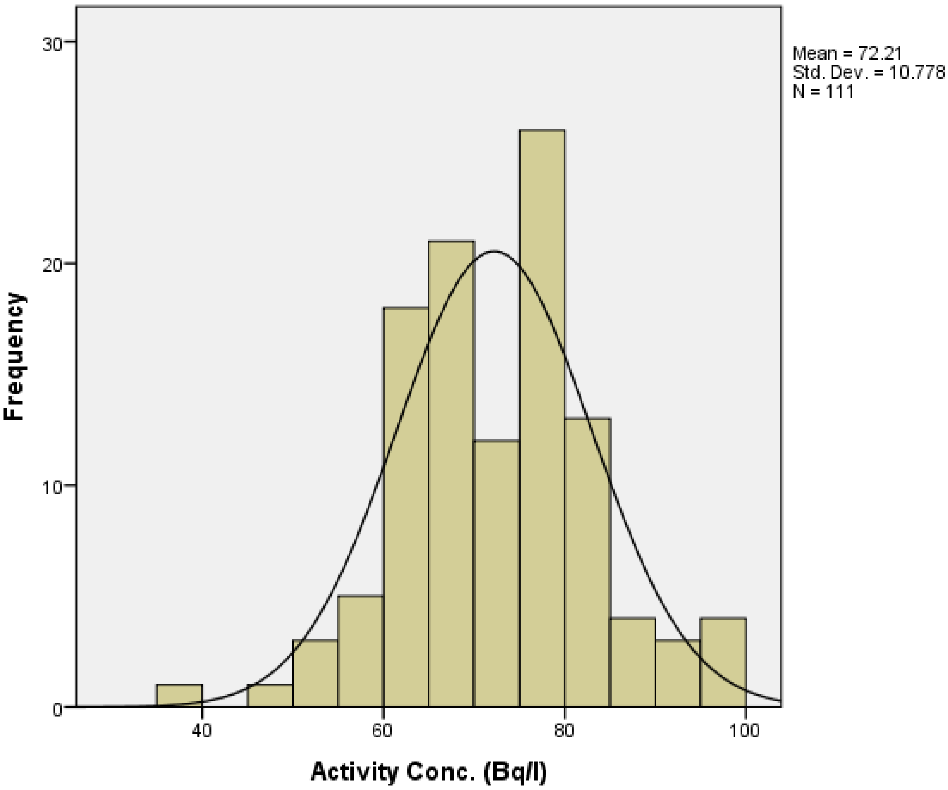

Figure 2: Distribution of the Radon Concentration Measured data.

Figure 3 below shows the box plot of radon activity concentration data based on different geological formations. It can be seen that, most of the data are positively skewed with maximum and minimum values obtained on geological formations G8 (Silicified sheared rock) and G7 (Sandstone) as indicated by the upper and lower whiskers respectively. Outliers can also be observed on G8 and G6 as indicated by the dots on their respective lower whiskers.

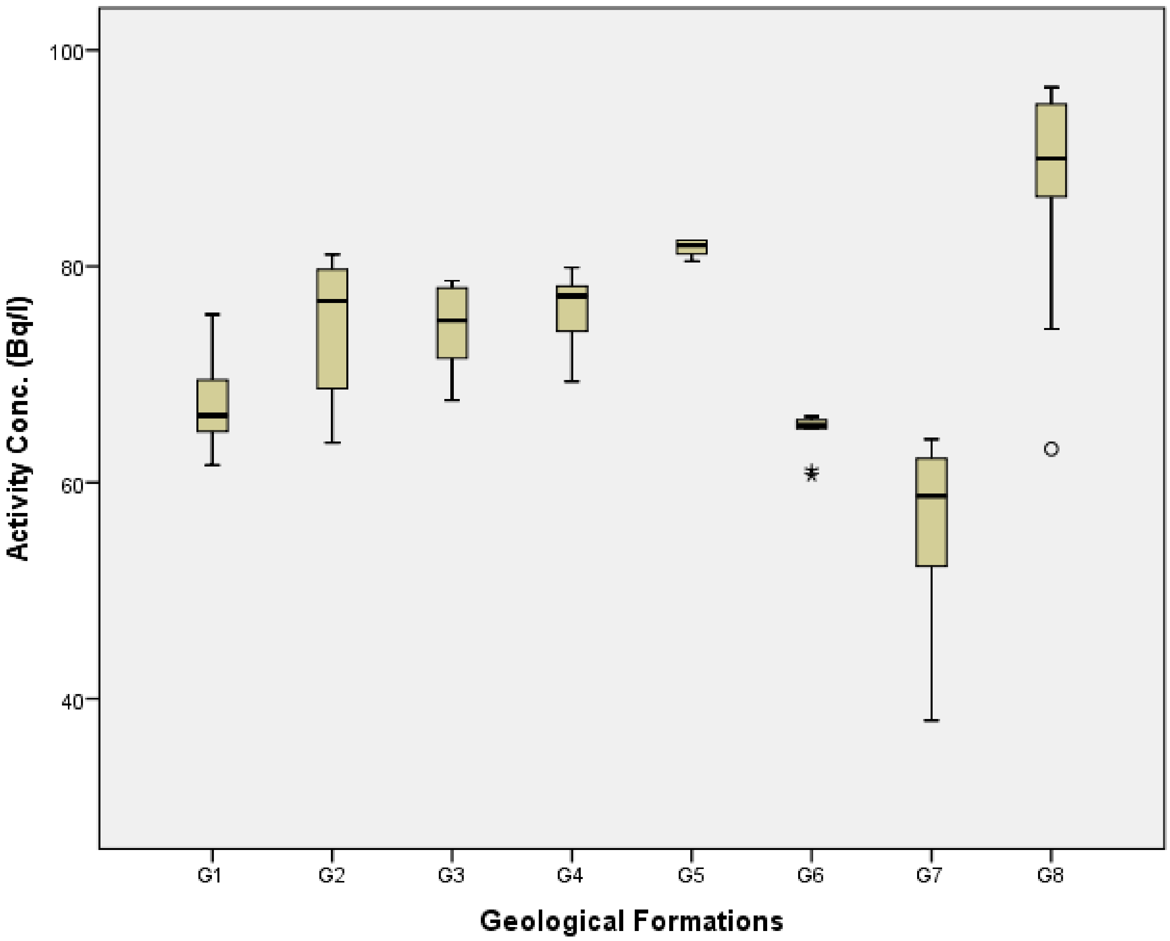

Figure 3: Box plots for the Measured Radon Activity Concentrations Based on Different Underlying Geological Formations

It can be observed from the Table that, the high F-test values indicates that the 22Rn activity concentrations for the geological formations are normally distributed and are statistically significant with a probability value less than the critical value of ($\alpha = 0.05$).

Table 3: ANOVA results for 222Rn Concentrations for the Geological Formations

	Sum of Squares	Df	Mean Square	F	Sig.
Between Groups	9519.463	7	1359.923	42.997	.000
Within Groups	3257.752	103	31.629		
Total	12777.215	110			

This means that the null hypothesis is rejected, thus, strong differences exist between the various geological formations in terms ^{22}Rn activity concentration. Since the null hypothesis is rejected, then it becomes necessary to identify which geological formation differ from another. In line with this, T and multiple comparison tests were also conducted in order to compare the variations in mean ^{22}Rn activity concentration values for the geological formations.

Table 4: T-test results of ^{222}Rn concentration for geological formations

Geological formations		Mean Difference (I-J)	Std. Error	Sig.
G1	G2	33.294*	3.731	0
	G3	41.946*	4.53	0
	G4	14.537*	4.038	0
	G5	47.712*	5.776	0
	G6	5.934	5.279	0.261
	G7	25.023*	3.599	0
	G8	57.545*	4.948	0

G2	G3	8.651*	3.744	0.021
	G4	18.757*	3.13	0
	G5	14.418*	5.182	0.005
	G6	39.228*	4.622	0
	G7	58.317*	2.539	0
	G8	24.251*	4.24	0
G3	G4	27.409*	4.05	0
	G5	5.767	5.784	0.319
	G6	47.879*	5.288	0
	G7	66.969*	3.613	0
	G8	15.599*	4.958	0.002
G4	G5	33.175*	5.407	0
	G6	20.471*	4.873	0
	G7	39.560*	2.972	0
	G8	43.008*	4.512	0
G5	G6	53.646*	6.387	0
	G7	72.735*	5.088	0
	G8	9.833	6.117	0.108
G6	G7	19.089*	4.516	0
	G8	63.479*	5.65	0
G7	G8	82.568*	4.124	0

Table 5: Duncan's Multiple Range Test Analysis Results for ^{222}Rn Concentrations

	Geology types	N	Subset for alpha = 0.05				
			A	b	c	d	E
Duncan[a,b]	G7	17	56.834706				
	G6	11		64.669091			
	G1	15		67.289333			
	G2	17			73.910588		
	G3	15			74.471333		
	G4	12			75.943333		
	G5	10				81.738000	
	G8	14					87.588571
	Sig.		1.000	.230	.383	1.000	1.000

Table 5 above presents the homogenous subsets of the means from the Duncans Multiple Range Test (DMRT) using a harmonic mean sample size of 13.408. It can be observed that, majority of the means differ from one another significantly with exception of few that fall under same group as can be seen in the table. This result reaffirms the earlier result obtained from the Analysis of Variance for the means.

Table 6: Comparison of Some Studies on ^{222}Rn Activity Concentration in Nigeria with the Present Work

Water type	^{222}Rn Conc.(Bql^{-1})	Region	Reference
Ground water	69 ± 3.0	Katsina State, Nigeria	Present Study
Ground water	10	Sokoto, Nigeria	Adetoto *et al.*, 2021
Ground water	19 ±7	Lagos, Nigeria	Mostafa *et al.*, 2022
Ground water	7.0 ± 0.3	Kaduna, Nigeria	Bello *et al.*, 2016
Ground water	7.4± 2.0	Zaria, Nigeria	Garba *et al.*, 2012
Ground water	64-69	Dutsinma,, Nigeria	Joseph *et al.*, 2018
Ground water	0.2-78.5	Ijero, Ekiti State, Nig.	Akinnagbe, *et al.*, 2018

CONCLUSION

This study establishes, statistically the relationship between radon activity concentrations in borehole and underlying geological formations of Katsina State. Normal distribution test, ANOVA, T-test and Duncan Posthoc test were carried out and the results showed a strong correlation between underlying geological formations and Radon concentrations. This strong correlation between geological formations and the concentration of ^{222}Rn in the borehole water found, can said to be as result of constant interaction of water with the corresponding underlying rock type as acid intrusive rocks are always associated with higher natural radionuclides concentrations and sedimentary rocks with lower concentrations. Furthermore, comprehensive studies should be carried out to assess the ^{222}Rn concentration in the different water sources across the state.

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