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Assessment of the Specific Activity of Alpha- and Beta-emitting Radionuclides in Groundwater, Anka, Nigeria

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ABSTRACT

Introduction: After the lead poisoning outbreak came to light in Zamfara State, Nigeria, people living near gold mines were worried about environmental safety, especially drinking water quality. This study examined the gross alpha and gross beta activity concentrations in groundwater in different locations of Anka, Zamfara State, Nigeria, to measure the possible radiation dose and potential health effects.

Material and Methods: In this study, 32 water samples were collected from hand dug wells and boreholes in Anka, Nigeria, through stratified random sampling method. The ISO 9696 and ISO 9697 methods were adapted using Eurysis system-multiple-channel-gas-filled proportional counter to measure gross alpha and gross beta activity concentration.

Results: The ranges of alpha and beta activity concentration in groundwater of the area were 0.114 to 3.698 Bq/l and 0.071 to 4.823 Bq/l with the geometric means of 0.961 Bq/l and 2.134 Bq/l, respectively. These amounts were higher than the reference limits of 0.5 Bq/l and 1 Bq/l for gross alpha and beta activity concentrations, respectively. Additionally, the total annual effective dose equivalent was more than that (0.1 mSv/y) of recommended by World Health Organization (WHO).

Conclusion: The mean concentrations of alpha and beta activities in the samples were above the limits recommended by WHO. These excessive radiations might negatively affect the environment and inhabitants.

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Introduction

Water is vital to life on the Earth, which assists in the distribution and movement of natural radionuclides. Water is undoubtedly the most fundamental necessity of life, and its importance cannot be overemphasized. Water may be contaminated by both human activities, such as mining, sewage, industrial disposal, leaching, and fertilizer application, as well as naturally occurring sources. The disposed materials from these activities may contain radioactive materials, which contribute significantly to the background activity of the water bodies [1].

It is essential to assess radionuclide concentration in water to keep the public exposure to radiation as low as reasonably achievable. Groundwater is always in contact with rocks embedded within the Earth's crust; therefore, it usually carries naturally occurring radioactive materials (NORMs). The NORMs often disintegrate and thereby emitting alpha and beta particles and gamma radiation.

Water passes through the pore space in bedrocks or within the soil containing mineral deposits that might constitute some radioactive materials. Therefore, water sourced from deep wells and boreholes are expected to have very high concentration of radionuclides. So far, a series of lead poisonings occurred from 2010 in Zamfara State, Nigeria, as a result of environmental contamination from both artisanal mining and processing of gold found in lead-rich ore.

The local miners did not know the techniques to crush the ore and ground it to a powder. Accordingly, lead and lead compounds spread throughout the environment. According to the literature, blood lead level elevates due to the inhalation and ingestion of fine lead particles. The World Health Organization (WHO) confirmed lead poisoning in 80 villages of Zamfara State, Nigeria.

There are four stable isotopes of lead, namely, ^{204}Pb, ^{206}Pb, ^{207}Pb, and ^{208}Pb; ^{204}Pb is a primordial nuclide, while the others represent the ends of uranium series (or radium series), the actinium series, and the thorium series, respectively. These series represent the decay chain products of long-lived primordial ^{238}U, ^{235}U, and ^{232}Th, respectively [2]. ^{210}Pb has a half-life of 22.20 years, which is the longest half-life among the naturally occurring radioisotopes.

Therefore, any isotope of lead existing in gold ore can be among the sources of radiation in the groundwater because the miners typically wash gold

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ore within the rivers and ponds of their region. One of the major ways by which radionuclide from the environment gets into human body is radioactivity in ground water. This might lead to radiation-induced disorders [3] and is harmful for human. Consequently, a strong need is felt for a comprehensive study on radioactivity levels in the water systems of various environments. Such a review helps the government for controlling radiation-related diseases.

One of the primary goals of WHO and its member states is the right of having accession to safe drinking water for all people of different developmental stages, as well as social and economic conditions [4]. Determination of alpha and beta radiation in water is essential and will serve as a good indicator of radionuclides presence in water.

On the other hand, a very sophisticated process is required to identify an individual radioactive species and determine the concentration. This process is expensive and usually not justified, because levels of the radionuclide in most circumstances are indetectable. Therefore, a screening procedure is used as a more practical approach. First, the total radioactivity present in the form of specific activities of alpha and beta emitters is determined regardless of the specific radionuclide identity from the source of emanation. WHO (2006) set the screening level of gross alpha and beta activities in drinking water as 0.5 Bq/L and 1 Bq/L below which no further action is required, respectively.

A joint group was formed consisting of Centres for Disease Control and Prevention (CDC) in United States, Medicines Sans Frontieres (MSF), World Health Organization (WHO), United Nations Children's Fund (UNICEF), Zamfara State Ministry of Health (ZSMOH), Zamfara State Ministry of Environment (ZSMOE), and Zamfara State Ministry of Water Resources (ZSMWR). The mentioned group investigated lead concentration in blood, soil, and water in the study areas. However, they did not work on the radioactivity concentration in water.

Some researchers investigated the level of naturally occurring radionuclide materials in soil from some mining sites in Zamfara state, but their work did not cover this area (Anka LGA). In addition, no investigation was carried out on water [5]. Udiba et al. assessed heavy metals in the soil of Dareta village, Zamfara state [6]. Their work presents the specific activities of alpha and beta emitters in groundwater from Anka Local Government. Furthermore, they compared their results with WHO maximum contaminant limits of 0.5 Bq/l and 1.0 Bq/l for alpha and beta activities, respectively.

Theoretical Considerations

Gross nuclides activity indirectly describes the relationship between radionuclide concentration with gross alpha and beta activities. In this regard, estimation of gross activity conversion factor (GCF) is necessary.

For estimation of gross activity conversion factor some assumptions are considered:

1. Beta particles are electron particles emitted from nuclides, and decay of these particles gives rise to a spectrum of particles with kinetic energies ranging from zero to maximum. Therefore, gross activity measurement just detects the emitted particles with kinetic energy. Particles with average energy above 100 keV are known to be the detectable particles (ISO standard 2008 and USEPA 1997 consider 300 KeV and 200 keV, respectively as the minimum detectable energy)
2. The contribution of internal conversion electron (CE) accompanied by gamma decay, will also be considered. This means that the CE with energy of higher than 100 keV is also taken into account.
3. Electron capture (EC) decay is accompanied by electron emission called Auger electron. These electrons are ignored due to their energies of below 100 keV.
4. Electrons emitted in other ways, such as pair production, photoemission, and Compton scattering from the gamma radiation interactions are ignored, because are too weak to play role in the gross beta measurement.

The equation below defines the gross activity conversion factor for radionuclide with stable decay nuclide

$$T = \sum_i y_i \quad (1)$$

Where, T is the GCF and y_i is the branching ratio of beta or CE with average energy above 100 keV.

For cascade decay, the gross beta contribution from the decay nuclide should be considered. Supposing cascade decay:

$$N_1 \rightarrow N_2 \rightarrow \cdots N_i \ldots N_N$$

Where N_N is stable, the GCF can be defined as:

$$T = \sum_j \sum_i \frac{y_{i,j} A_i(t)}{A_i(t)} \quad (2)$$

Where $y_{i,j}$ is the branching ratio of beta or CE with average energy greater than 100 keV for N_j and A_j is the activity of N_N. Then we obtain:

$$A_j(t) = \lambda_j N_j(t) = N_o \sum_{k=1}^{j} C_k e^{-\lambda_k t} \quad (3)$$

$$C_k = \prod_{l=1}^{j} \lambda_l / \prod_{l=1, j\neq k}^{j} (\lambda_l - \lambda_k). \quad (4)$$

The activities of $y_{i,j}$ and N_j can be written as:

$$A_1(t) = \lambda_1 N_1(t)$$

$$= \lambda_1 N_o e^{-\lambda_1 t} \quad (5)$$

$$A_2(t) = \lambda_2 N_2(t)$$

$$= \lambda_2 \frac{\lambda_1}{\lambda_1 - \lambda_2} N_o (e^{-\lambda_1 t} - e^{-\lambda_2 t}) \quad (6)$$

For cascade decay with N=2, the GCF is given as:

$$T = \sum_{1,i} y_i + \sum_{2,i} \frac{y_{2,i}\lambda_2}{(\lambda_2 - \lambda_1)^{(1-e^{-(\lambda_2-\lambda_1)t}}} \quad (7)$$

It is shown that GCF is a function of time. In this type of decay scheme three conditions may predominate, including transient equilibrium, secular equilibrium, and state of no equilibrium.

For $\lambda_1 < \lambda_2$ the parent nuclide decays slower than the progeny nuclide, which is consistent with the transient equilibrium. For sufficiently large values of t, the GCF can be written as:

$$T = \sum_{1,i} y_i + \sum_{2,i} y_{2i}\lambda_2/(\lambda_1 - \lambda_2) \quad (8)$$

For $\lambda_1 \ll \lambda_2$ the secular equilibrium is met and GCF can be calculated by

$$T = \sum_{1,i} y_{1,i} + \sum_{2,i} y_{2,i} \quad (9)$$

For $\lambda_1 > \lambda_2$ the parent nuclides decay faster than the progeny nuclides and no equilibrium is observed. Activity of the decay products will increase and accumulate to a maximum amount, followed by a slow decay. GCF from the equation (7) and the activity ratio of A_2/A_1 will increase to infinite. In this situation, only contribution of the parent nuclide is considered [7].

Materials and Methods

Research Setting

As shown in Fig. 1, the study area, is located in Zamfara, a state in the North-western part of Nigeria on longitude 006030''11''–007^{0}00$^{'}$03$^{''}$E and latitude 12^{0}39$^{'}$18$^{''}$–12^{0}46$^{'}$01$^{''}$N. The state is a part of the geological belt of pre Cambrian Paleo State era, formed as the result of metamorphosis and igneous activities. The granite areas include two parts, namely the younger and the older granites. The older granites are more widespread and form smooth round hills occasionally rising to 200 meters. Kotorkoshi and Tsafe could be mentioned among these hills, which characterize the landscape of basal complex area. The younger granites are attributed to the Jurassic age and intrude into the basement complex of the plateau areas as in Yandoto. Some metasediments consist of phyllite, quartzite, and metconglomerates that have resulted in limestone, clay, graphite, stone, and coal [8].

Counting System

The gross alpha and beta activities were counted using Eurisys Measure-IN20 multiple-channel gas-filled proportional counter. The system is a multiple-channel detector of alpha and beta with low background designed and made by Intertechnique Courtaboeuf cedex, France.

It is a 450 μg/cm^3 thick window of 60 mm diameter. The radiation within the measuring environment was estimated to be less than 1 nSv/hr. The counting system incorporates an anti-coincident guard count used to determine the influence of high-energy cosmic radiation that enters the measuring environment. The counting gas is a mixture of argon and methane gases at the ratio of 9 to 1.

Compound measurement of both alpha (α) and beta (β) on compound sources can be selective, sequential, or simultaneous. The procedure involves entering present time, some cycles, and the operational voltage. The counting characteristics (channel efficiency and background count rate), the volume of used sample, and sample efficiency were also entered. The selective measurement was adopted for counting both alpha and beta activities with the samples counted for 5 cycles of 2700 sec. Additionally, high voltages of 1650 V and 1700 V were applied for the gross alpha and gross beta counting, respectively. Principles of the counting system is depicted in Fig. 2.

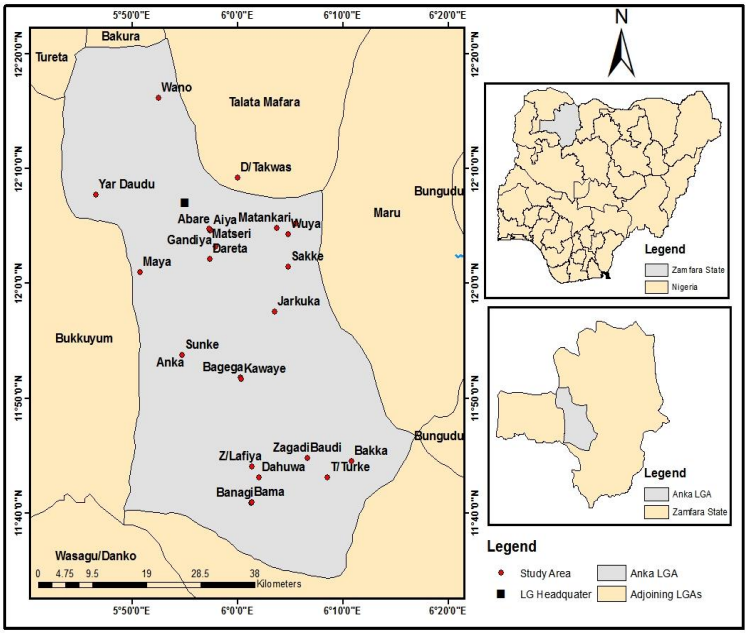

Figure 1. Map of the study area (Source: GIS Lab. Department of Geography UDUS 2018)

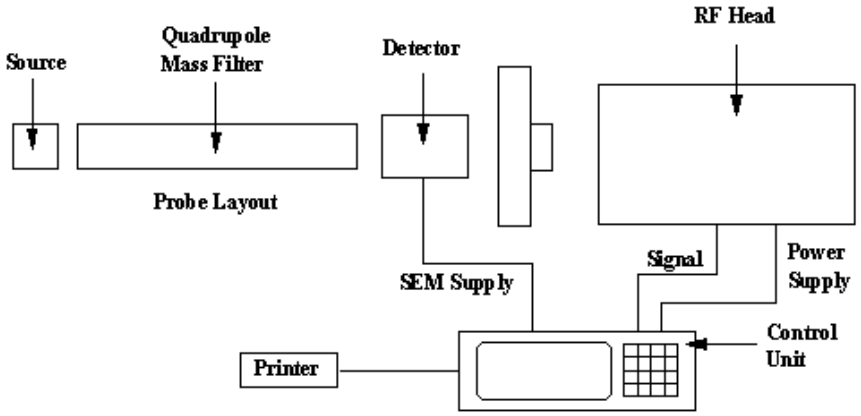

Figure 2. Block diagram of proportional gas counter

Calibration Standards

The alpha standard sources are plutonium-239 alpha in form of discs with diameter of 38 mm and thickness of 3 mm. They contain a range of impurities varying from 0.74-0.82% of Am-241 and Pu-240. The activity changes from 133.3 to 185.5 Bq at 2π-steradians in the eight channels. The identification serial numbers of the sources are EBSB20/50026, 50050, 50051, 50052, 50053, 50054, 50055, and 50056, respectively. The activity measurements were certified by CERCA's Radioactivity Standards Laboratory (LEA) in France with the calibration certificate No. CT001/1285/1920-1927.

The beta standard sources are strontium-90 in form of discs 38 mm in diameter and an active film of 12 mg/cm^3 thickness. Eight sources of activity varying from 105.1 to 117.7 Bq at 4π-steradians exist for the eight channels. The radionuclide impurity in each of them is less than 0.1%. The serial numbers of sources are EBSB20/14529, 14530, 14531, 14532, 14535, 14536, 14537, and 14539, respectively. Similar to the alpha measurements, the CERCA LEA Laboratories in France certified all measurements with certificate No. CT001271/00/1778-1783. The alpha and beta standards were used to calibrate the proportional counter.

Sampling and Analysis

Thirty-two (32) water samples were collected from hand-dug wells and boreholes in the area by stratified random sampling method. In order to minimize contamination of the container, the sample container was rinsed with distilled water before sample collection. About 1% of the container was left empty to allow sufficient space for thermal expansion.

Immediately after collection, almost 10 ml of nitric acid (0.315 molar) was added for preservation to each sample. This could minimize precipitation and particulate absorption by the wall of the container. Adding nitric acid led to water pH rise to about 6.8 pH. The samples were tightly covered and kept in the laboratory until the time of analysis. All the samples were prepared and analysed at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria.

The analysis of both alpha and beta activities was carried out using ISO9696 and ISO9697 methods. These two methods were specified by the International Organization for Standardization (ISO) for the determination of gross alpha and beta activities in non-saline waters. Stabilization of the samples was achieved through acidification. Next, the combinations were evaporated to get almost dried before being ignited at 350°c. A portion of the residue was transferred to a planchet and then into the counting system previously calibrated using alpha and beta emitting standards [9, 10].

To obtain the sample preparation efficiency, weight of the residue was calculated as the difference between W_{B+S} (weight of planchet plus sample post-evaporation) and W_B (weight of empty planchet). The ratio of the difference between the weights of the residue divided to 0.071g as specified by ISO which is multiplied by 100 gives the sampling efficiency as shown in equation 10 below.

$$\text{Sampling Efficiency}=\frac{(W_{B+S}-W_B)}{0.077}\times 100 \qquad (10)$$

Where W_B is the weight of empty planchet, W_{B+S} is the weight of the empty planchet plus the sample after evaporation and 0.077 (mg) is the expected mass of the residue in the planchet.

Detectors Calibration

Using the alpha and beta manufacturer's calibration standards (^{239}Pu and ^{90}Sr), plateau test was conducted in alpha only mode and beta only mode, respectively. The test was carried out for five cycles within 1800 s each. The operation efficiencies for the eight channels of the counter were found as demonstrated in Table 1. The results show the mean efficiencies of 34.72% and 39.88% for the alpha and beta counts in alpha only and beta only modes, respectively. The obtained efficiency values are favourable for this type of counting system. Therefore, the single mode operation was adopted for conduction of the present study.

Table 1. Channel efficiency

Channel	Efficiency In alpha only mode (%)	Efficiency In beta only mode (%)
1	34.85	46.47
2	33.85	35.39
3	33.3	36.33
4	35.64	38.79
5	38.20	40.66
6	31.97	42.94
7	33.79	43.58
8	36.17	34.88

Table 2. Background activity

Channel	Background in alpha only mode (Bq/l)	Background in beta only mode (Bq/l)
1	0.259	1.47
2	0.254	1.27
3	0.232	1.13
4	0.250	1.21
5	0.240	1.25
6	0.207	1.02
7	0.111	1.76
8	0.172	0.92

Background Radiation

The background radioactivity of the environment was assessed to be used in the subsequent measurements. For this aim, the adopted operational counting mode system was utilized and the activity of the clean empty planchets was evaluated. Table 2 displays the background activity results of the studied environment. The findings are indicative of reproducibility in all the counter channels.

Furthermore, average background radioactivity of 0.216 and 1.254 Bq/l for alpha and beta were found in alpha only and beta only modes, respectively. The obtained results represent the environment and could be used in the subsequent measurements of the water samples.

Results

The multiple-channel proportional gas counter used for this study had initially been characterized for evaluating gross alpha (α) and beta (β) activity concentrations. As mentioned, alpha and beta activity background measurements were performed in the alpha and beta only modes, respectively.

Activity Concentration

Results of the present study regarding the gross alpha and beta activity concentrations from the boreholes and wells of the sampled area are demonstrated in Table 3. The errors quoted in the table represent the standard deviation from the measurements repetition. Names of the villages from which the samples were collected, the elevation and coordinates of the points of sample collection, as well as the distribution of the activity concentrations within the studied area are shown in the table.

The average alpha and beta activity concentrations had an interval of 0.114±0.2 to 3.698±1.10 Bq/l and 0.071±0.01 to 4.823±1.55 Bq/l, respectively. The gross activity concentrations obtained in this study were compared with those of other locations as indicated in Table 3. Moreover, the overall distribution of measured gross activities in groundwater from various locations is shown in Fig 3. Figures 4 and 5 separately demonstrate the bar charts related to the distribution of alpha and beta activity concentrations, respectively. The correlation between alpha and beta activity concentrations is also displayed in Fig 6.

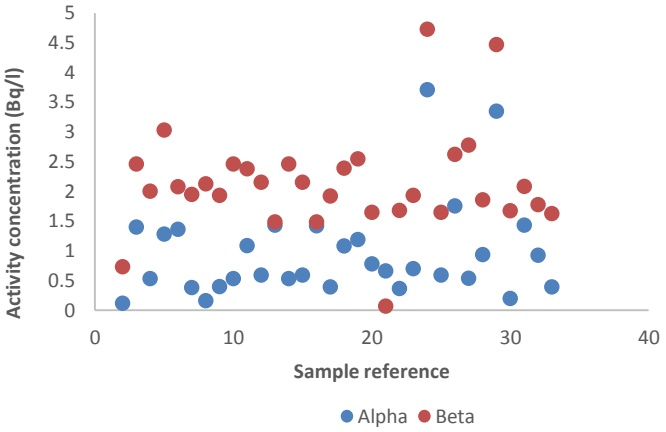

Figure 3. Distribution of measured gross alpha and beta activity concentrations in groundwater from various locations

Table 3. Average gross activity concentrations of alpha and beta in water samples

S/N	Sample Name (villages)	Elevation (m)	Coordinate Location	Alpha Activity (Bq/l)	Beta Activity (Bq/l)
1	T/Tsaka	378	N12.42475^{0}E005.62784^0	0.114± 0.02	0.751±0.67
2	R/Gero	389	N12.86268^0 E005.33627^0	1.396±0.39	2.455± 0.78
3	Wano	385	N12.26856^0 E005.87476^0	0.532±0.12	2.102±0.45
4	Karumbare	388	N12.77826^0 E005.97475^0	1.291±0.13	3.012±0.51
5	K/Maje	378	N12.52286^{0}E005.72624^0	1.351±0.12	2.121±1.31
6	D/Takwas	359	N12.15293^0 E005.99924^0	0.380±0.13	1.956±0.59
7	Bakka/Daji	414	N11.74086^0 E006.18000^0	0.149±0.04	2.112± 0.68
8	DahuwaSaulawa	408	N11.71807^0 E006.03350^0	0.392±0.11	1.930±0.60
9	Zagadi	392	N11.74561^0 E006.10976^0	0.540± 0.16	2.501±0.77
10	Banaga	415	N11.68021^0 E006.02080^0	1.101±0.24	2.386±0.78
11	T/Turke	410	N11.71714^0 E006.14111^0	0.594±0.10	2.202±0.70
12	Bagega	399	N11.86335^{0}E006.00443^0	1.445±0.32	1.491±0.49
13	Baudi	395	N11.74561^{0}E006.10976^o	0.523±0.20	2.441± 0.81
14	FararKasa	415	N11.71014^0 E00614110^0	0.602±0.22	2.132 ± 0.69
15	Kawaye	404	N11.86003^{0}E006.00525^0	1.412±0.31	1.521 ± 0.54
16	Z/Lafiya	402	N11.7329^{0}E006.022610^0	0.395±0.12	2.112 ± 0.561
17	Bama	401	N11.68121^{0}E006.02181^0	1.103±0.23	2.411 ± 0.78
18	TungarSakke	374	N12.02380^0 E006.07976^0	1.183±0.21	2.521±0.82
19	Dareta	357	N12.03474^{0}E005.95581^0	0.787±0.22	1.723±0.57
20	Maya	346	N12.01635^{0}E005.84522^0	0.650±0.22	0.071±0.01
21	Mai Rakumma	364	N12.05249^{0}E005.96522^0	0.344±0.11	1.723±0.48
22	'Yarssabaya	354	N12.08633^{0}E006.09205^0	0.701±0.04	1.945±0.60
23	Jarkuka	350	N11.95846^{0}E006.05853^0	3.698±1.10	4.823± 1.55
24	Wuya	353	N12.07071^{0}E006.07976^0	0.612±0.21	1.654±0.55
25	Yan matankari	348	N12.07947^{0}E006.06115^0	1.762±0.55	2.632±0.82
26	Abare	342	N12.07762^0 E005.95633^0	0.523±0.23	2.876±0.81
27	Maimayi	343	N12.07703^0 E005.95672^0	0.921±0.33	1.943±0.66
28	Gandiya	342	N12.07679^0 E005.95622^0	3.351±1.21	4.526±1.44
29	Aiya	343	N12.07615^0 E005.95732^0	0.212±0.54	1.698±0.81
30	Matseri	340	N12.07851^0 E005.95528^0	1.422±0.37	2.113±0.71
31	TungarYarDaudu	341	N12.12789^0 E005.77624^0	0.911±0.21	2.221±0.52
32	Sunke	340	N11.89601^{0}E005.91208^0	0.403±0.11	1.702±0.51

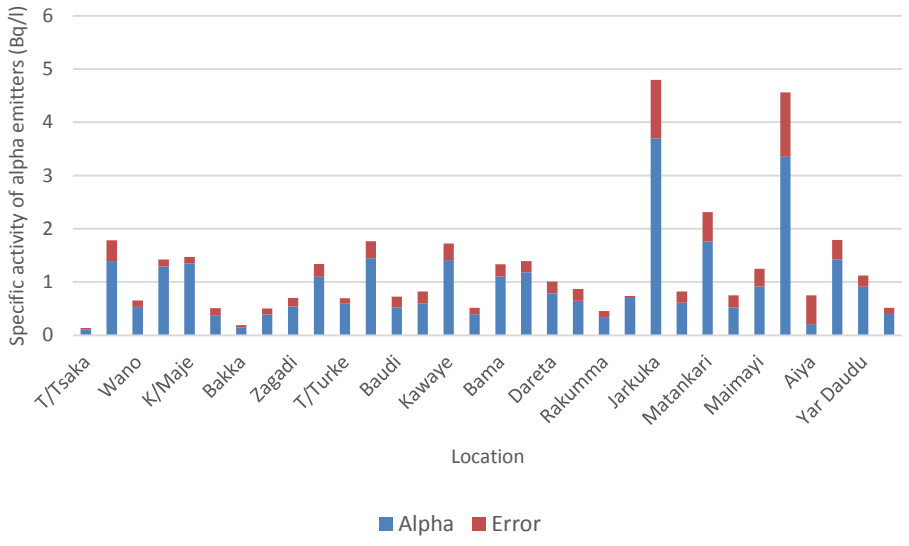

Figure 4. Distribution of alpha activity

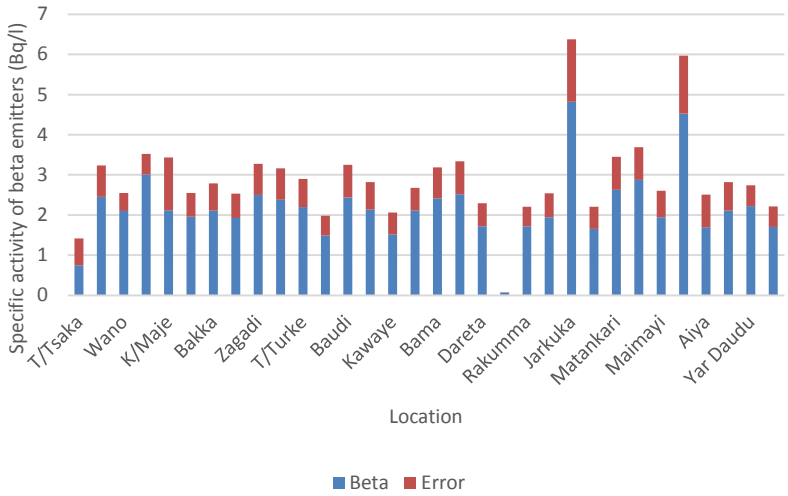

Figure 5. Distribution of beta activity

Table 4. Effective equivalent dose in all the sampled locations

Location	Effective equivalent dose due to radium-226 (mSv)	Effective equivalent dose due to beta radionuclides (mSv)	Total effective equivalent dose (mSv)
T/Tsaka	0.0233	0.7566	0.7799
R/Gero	0.2853	2.4732	2.7585
Wano	0.1087	2.1176	2.2263
Karumbare	0.2639	3.0343	3.2982
K/Maje	0.2761	2.1367	2.4128
D/Takwas	0.0776	1.9704	2.0481
Bakka	0.0305	2.1276	2.1581
Dahuwa	0.0801	1.9443	2.0244
Zagadi	0.1104	2.5195	2.6298
Banagi	0.2250	2.4036	2.6287
T/Turke	0.1214	2.2183	2.3397
Bagega	0.2954	1.5020	1.7974
Baudi	0.1069	2.4591	2.5659
FararKasa	0.1230	2.1478	2.2708
Kawaye	0.2886	1.5323	1.8209
Z/Lafiya	0.0807	1.1202	1.2009
Bama	0.2255	2.4288	2.6543
Sakke	0.2418	2.5396	2.7815
Dareta	0.1608	1.7357	1.8966
Maya	0.1328	0.0715	0.2044
Rakumma	0.0703	1.7357	1.8061
‘Yarssabaya	0.1432	1.9594	2.1026
Jarkuka	0.7558	4.8586	5.6145
Wuya	0.1250	1.6662	1.7913
Matankari	0.3602	2.6515	3.0116
Abare	0.1069	2.8973	3.0042
Maimayi	0.1882	1.9573	2.1456
Gandiya	0.6849	4.5594	5.2444
Aiya	0.0433	1.7105	1.7539
Matseri	0.2907	2.1286	2.4193
YarDaudu	0.1862	2.2374	2.4236
Sunke	0.0824	1.7146	1.7970
Average	0.1967	2.1661	2.3629

Effective Dose

The average annual effective dose due to drinking the water that contains specific activities of radionuclides emitters of alpha and beta particles was determined by computing the mean individual annual committed effective doses. The latter doses result from significant radionuclides emitting alpha and beta in U-238 and Th-232 decay series [11]. The total annual committed effective dose is estimated by equation 11.

$$E_{avg(\alpha,\beta)=\sum_i^{R(\alpha,\beta)}(A_{i(\alpha,\beta)})(DCF)_{i(\alpha,\beta)}(730)} \quad (11)$$

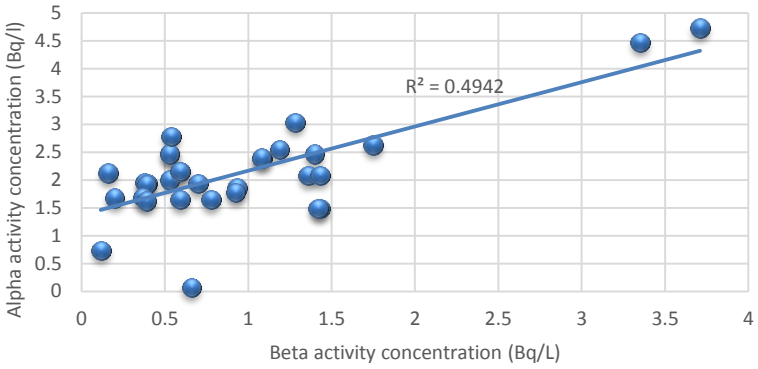

Figure 6. Correlation between alpha and beta activity concentrations

Table 5. Gross activities in comparison with other places

Location	Measured Activity (Bq/l)				Number of samples
	Alpha		Beta		
	Min	Max	Min	Max	
Zaria	0.00056	0.043	0.036	0.620	32
Kano	0.002	0.010	1×10^{-5}	1.8×10^{-4}	40
Jos	0.100	6.050	0.250	9.640	48
Mina	0.001	0.024	0.072	0.558	20
Sokoto	0.010	6.000	0.350	7.650	40
Belgium	5.6×10^{-3}	2.7×10^{-2}	5.6×10^{-2}	0.72	30
UK	0.03	0.15	0.30	0.33	30
Netherlands	0.03	0.06	0.04	0.14	5
This Work	0.116	3.71	0.068	4.725	32
WHO accepted value	0.50		1.00		

Where E_{avg} represents the total annual committed effective dose in a non-saline water, A_i is the gross alpha or beta activity concentration, and $(DCF)_i$ is considered as the dose conversion factor for intake of particular natural radionuclides by an adult [12]. An average healthy adult is assumed to be taking 2 L of water per day resulting in 730 L per annum. Table 4 shows the effective equivalent dose in all the sampled locations.

Discussion

In the present study, gross alpha and beta activities in majority of the samples exceeded the screening limit set by WHO. Ninety percent of the samples were reported to be above the 0.5 Bq/L limit for alpha activity in water and only 10% were below the threshold. Furthermore, 96% of the samples showed beta activity higher than the limit of 1.0 Bq/L and only 4% were found to have beta activity lower than the threshold.

This could be attributed to the intensive mining activity taking place in the study area. Moreover, it is a clear indication of possible percolation of radionuclides from rocks to the ground water of the region. Furthermore, it is important to note that the beta activity concentration is higher than the alpha concentration at each location. The latter fact is illustrated in figure 3 and is indicative of the relative distribution of alpha and beta activity in different locations of the current study area. This suggests that the beta-emitting radionuclides may dominate the contaminants.

The bar charts of alpha and beta activity concentrations in the samples of ground water collected from different villages of Anka Local Government Area are demonstrated in figures 4 and 5, respectively. It could be concluded from the charts that variation exists in concentrations of alpha and beta activities in the ground water of different locations of the study area.

It could be observed that the samples collected from Jarkuka and T/Tsaka villages have the highest and the lowest level of alpha radiation concentration, respectively. Moreover, the sample collected from Jarkuka village has the highest level of beta radiation while the sample obtained from Maya village has the lowest concentration of beta radiation. There are extensive mining activities around the locations that indicated high levels of gross alpha and beta activity concentrations. This could imply that mining activity in an area may have significant roles in contamination of the drinking water. This is consistent with the trend of gross alpha and beta activities at different locations of the study area.

A weak linear correlation was found between gross alpha and beta activities in the water as indicated in Fig 6. This might confirm that different radionuclides could be responsible for contamination of the drinking water.

It is believed that radium accounts for about 50% of the annual effective dose induced by gross alpha activity in the consumption water [13, 14]. We considered the aforementioned assumption in our work because the facility used for determining the gross activity concentration was not able to detect particular

radionuclides in the water samples. It should be noted that ^{210}Pb and ^{228}Ra were regarded as the major contributors to the gross beta activity. Therefore, the DCF was taken as 2.8×10^{-4} mSvBq^{-1} for ^{226}Ra and as 6.90×10^{-4} mSvBq-1 for both ^{210}Pb and ^{228}Ra [15].

The calculated effective doses attributed to gross alpha and beta activities are shown in Table 4 with the range of 0.024–0.758 mSv and 0.069–4.760 mSv, respectively. The total effective equivalent doses at all locations of this study were relatively too high. It could be concluded that drinking water from this area may be associated with a very high risk. The recommended dose level (RDL) of the committed effective dose from consumption of drinking water within one year is 0.1 mSv. The obtained values in all the locations exceeded this reference level significantly resulting in unsafe drinking water.

According to the findings of the present study, the maximum specific activities caused by radionuclides emitting alpha and beta particles in the ground water of the studied area are 3.698 and 4.823 Bq/l, respectively. The mentioned results are higher than the values obtained from some places in Nigeria, such as Zaria (0.043 and 0.620 Bq/l) and Kano (0.010 and 1.8×10^{-4} Bq/l) [16, 17,] as shown in Table 5. However, the mean values of the alpha and beta activity concentrations in the present study compare favourably to those obtained in some other investigations in Nigeria, including Jos [18] (6.050 and 9.640 Bq/l) and Sokoto [19, 20] (6.000 and 7.650 Bq/l).

These results may be due to some similarities between the areas of our study and those evaluated in Jos and Sokoto. It should be mentioned that Jos is known to have geographical features of high mountains and rocks. Sedimentary and igneous rocks often contain radioactive materials that can play role in both alpha and beta activities in the ground water. Moreover, there are mining activities in that area similar to the conditions of this study.

Concerning Sokoto, this region is invaded by phosphate rocks known as Sokoto phosphate. In addition, farmers use a fertilizer, which is the by-product of phosphate and contains potassium-40. This is considered as a strong emitter of beta and gamma rays [21].

Higher concentrations of alpha and beta activities found in most of the collected ground water samples is attributed to the mining activity in this region. As mentioned before, gold is the primary mineral that is being mined in the area. However, lead is discovered to be coming along with the gold ore. The possible radioactive lead isotopes and other possible radioactive materials (e.g.; U, Th, and K) may be part of the factors responsible for the high level of alpha and beta activity, as well as the high effective dose in the ground water of this area.

Furthermore, the high concentration of alpha and beta activity can also be related to the geology of the area, which consists of granite rocks. Granite rocks are known to contain high concentrations of uranium, thorium, and potassium. Moreover, a common agricultural pollutant like nitrites, which are ubiquitous in agricultural runoff can lead to a chain reaction in aquifers. The situation can free up naturally occurring uranium and is a potent factor for increased radioactivity in drinking water and some crops.

Conclusion

In the current study, thirty-two ground water samples were collected from different settlements in Anka Local Government Area Zamfara State, Nigeria. The ISO9696 and ISO9697 methods of alpha and beta activity analysis in non-saline water were applied to determine alpha and beta activity concentrations. According to the results obtained from this study, the alpha and beta activity concentrations are high in the ground water of this area and exceed the safe limits of 0.5 and 1 Bq/l defined by WHO for alpha and beta, respectively.

Furthermore, the obtained annual effective equivalent dose was significantly higher than the specified limit of 0.1 mSvyr^{-1}. Consequently, the high activity concentration in the ground water of this area has the potential to negatively impact the health of millions habitants in this area. As a result, it is recommended to determine the radionuclides responsible for the high activity concentrations and testing the groundwater frequently.

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