Journal of Scientific Research & Reports

18(5): 1-14, 2018; Article no.JSRR.39193
ISSN: 2320-0227

Measurements of Gross Alpha and Beta Radioactivity in Surface Soil, Mineral Rock and Consumable Water around Mining Sites in Benue State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors AIO and GOA designed the study. Author AIO performed the statistical analysis, wrote the protocol and the first draft of the manuscript. Authors GOA and EO supervised and managed the analyses of the study. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2018/39193
Editor(s):
(1) Suleyman Korkut, Associate Professor, Department of Forest Industry Engineering, Duzce University, Division of Wood Mechanic and Technology, Turkey.
Reviewers:
(1) Ragip Adiguzel, Munzur University, Turkey.
(2) Veeravan Lekskulchai, Srinakharinwirot University, Thailand.
Complete Peer review History: http://www.sciencedomain.org/review-history/23827

Original Research Article

Received 8th December 2017
Accepted 20th February 2018
Published 26th March 2018

ABSTRACT

The concentration of gross alpha and gross beta radioactivity in surface soil, mineral rock and consumable water around mining sites in Benue state, Nigeria have been measured using protean instrument corporation (PIC) MPC 2000DP detector. The average activity for gross alpha ranged between 4.20±2.00 Bq/kg (coal) – 11.8±4.00 Bq/kg (salt) in soil and in mineral rocks the activity varies between 1.11±0.70 Bq/kg (lead) to 5.20±3.00 Bq/kg (limestone). The gross beta has an average activity ranges between 739.6±542.0 Bq/kg (lead) – 1703.3±152.20 Bq/kg (limestone) in soil and values of 245.3±171.5 Bq/kg (coal) to 1004.5±98.5 Bq/kg (barite) was obtained for mineral rocks. The average activity concentrations of gross alpha and beta in soil were compared with other literature values. Correlations were made among the variables (gross alpha and gross beta) to prove the interdependency or direct relationship in the investigated samples. In water samples, the calculated average value of gross alpha and gross beta activities varies from 0.0078±0.0036

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(barite) to 0.1620±0.2530 Bq/L (salt) and 0.2200±0.0123 (limestone) to 4.8500±0.1510 Bq/L (coal) respectively. The average activity concentrations of gross alpha in water in all mining fields were below the permissible levels stipulated by World Health Organization (WHO). The average annual committed effective dose from intake of water was calculated to study the dose level. The values obtained in limestone, barite, lead and salt mine fields were lower than the (WHO) recommended reference level (0.1mSv/y) while the value obtained in coal mine field was higher than the reference level. Consumable water around the coal mine field may pose a health risk as the ingested dose is quite high.

Keywords: Natural radioactivity; alpha and beta radioactivity; radioactivity of soil; mining site; radium, radionuclide; trace metal.

1. INTRODUCTION

The threats to public and the surrounding from radioactive contamination differ on the nature of the radioactive contaminant, the level of contamination, and the extent of the spread of contamination. Human activities such as mining, milling and processing of uranium ores and mineral sands, smelting of metalliferous ores, manufacture of fertilizers, drilling, and transportation, processing and burning of fossil fuels have raised the concentrations of naturally occurring radioactive materials in the environment [1,2].

Enhanced levels of these naturally occurring radionuclides might be present in the soil as well as surface and groundwater in areas that are rich in natural radionuclides. The soil is seen as a source of transfers of radionuclides through the food chain depending on their chemical properties and the uptake process by the roots to plants and animals [3] thus it is the elementary sign of the radiological status of the environment.

There is no doubt gamma rays have the highest penetrating power when compared to alpha and beta particles, the effects of alpha and beta particles within the body either through inhalation or ingestion are far more detrimental because of their ionising power [4]. The presence of radionuclides in water poses a number of health hazards, especially when these radionuclides are deposited in the human body through drinking. Dissolved radionuclides in water can emit particles (alpha and beta) and photons (gamma) which can gradually affect living tissues [4].

In nature, alpha particles come from the radioactive transformation of heavy elements long transformation chains produce several successive alpha and beta particle until the resulting nuclide has a stable configuration [5]. A specific alpha emitting radionuclide emits monoenergetic alpha particles of discrete energies and relative intensities, making it possible to identify each alpha emitting radionuclide by its alpha energy spectrum. The major amount of natural radionuclides entering into the human body via ingestion and contributes much to the exposure of man. Approximately 20% of radium isotopes and 10-15% of decay products of ^{238}U and ^{232}Th considered for this work reaches the bloodstream as reported by UNSCEAR [6-8] distributed to the whole body. Since the percentage distribution of annual intakes of uranium and thorium series radionuclides in food ranges between 4% to about 96% [9] accumulation of these radionuclides through the ingestion of the vital organs as food have significant health effects such as bone cancer, leukaemia and increase in blood pressure. Uranium has a chemical toxicity that predominately affects the kidneys [10,11]. Therefore, measuring the radioactivity in drinking water is of great interest in environmental studies [12].

This test serves as a preliminary screening stage and determines whether additional testing is advisable [13]. Gross alpha is much of concern than gross beta for natural radioactivity in water as it refers to the radioactivity of thorium- Th, uranium- U and radium- Ra as well as radon- Rn and their progeny [14].

The gross alpha radioactivity concentration in soil samples is defined as the total radioactivity of all alpha emitters. The value of gross alpha radioactivity originating from these alpha emitters in soil samples depends on the geological characteristic of the area, mineral composition and the type of activities in the area [4].

Natasa and others [15] study the gross alpha and gross beta activity in the soil sample from Drzljevo landfill in Republic of Srpska. The result shows that the gross alpha and beta activities

ranged between 66.7-102.4 and 285.7-607.4 Bq/kg. There is no regulation for limit values for gross alpha and beta activity in the soil, we cannot say this value implies certain level of hazard for the gross beta activity.

However, the gross beta activity in the sample of soil is great because of the presence of natural radionuclides ^{40}K in the soil [16].

Mangset and others [17] study the level of gross alpha and beta activity concentrations in groundwater supply in mining areas of plateau state. The result obtained shows that gross alpha and beta activity concentrations in most location from borehole and well water supplies are above the World Health Organization recommended guideline value. Also, Atsor and others [18] determine the concentrations of gross alpha and gross beta in underground water at Gboko and its environs, the results show that, the range of alpha activity in water in the area was 0.309 to 14.488 Bq/L, with geometric mean of 6.576± 0.328 Bq/L. The range of beta activity was 0.024 to 27.477 Bq/L with geometric mean, 11.16±0.42 Bq/L, they conclude that majority of the results do exceed the WHO and USEPA recommended standards.

Alpha emitters mixed to groundwater by filtrating through the soil may have contributed to the increased concentrations of gross alpha in well water samples.

The gross beta radioactivity in soil is due to the natural long-lived isotopes ^{40}K, ^{210}Pb and ^{228}Ra [4,19]. The presence of these radioactive elements may threaten the public and miners' health, and surroundings, there is need to document the level and extent of spread of these radioactive contaminations.

1.1 Study Area

The study areas are located in Benue State which lies within the lower river Benue trough in the middle belt region of Nigeria and is within the geographical points situated on longitude 7°47' and 10°0' East and Latitude 6°25' and 8°8' North. The geology of the study area is principal of sedimentary formation with pockets of basement complex which is made up of sandstones, mudstones and limestone that influences both surface and groundwater availability [20,21]. Benue State is endowed with solid mineral resources such as industrial minerals – barites, kaolin, gypsum, limestone; Energy mineral – coal, Chemical mineral – brine; Metallic mineral – wolframite, bentonite clay, lead and zinc etc, which are evenly distributed over the existing geographical location, some of which are yet to be mined. Mining activities are dominantly carried out in areas of limestone (Gboko), barite (Lessle), brine- rock salt (Akuana) and lead (Anyin) deposit fields while coal (Orokam) deposit fields are abandoned sites. The socioeconomic of the area covers agricultural activities, cattle rearing and fishing.

2. SAMPLE PREPARATION AND MEASUREMENT

A total of sixty samples were collected; thirty soil samples, ten mineral samples from host rocks and twenty water samples**.** Water samples were collected from rivers/streams in close proximity to the mineral sites and from the community public water supply sources (rivers, taps and wells). The samples were collected in 1-litre plastic containers with about 1% air space left for thermal expansion and these containers were rinsed with one litre acid to avoid containers' wall absorption of radioactivity [22] and to minimize the contamination of the sample from the original content of the container [23]. Soil and mineral samples were dried, pulverized and sieved by a 2mm mesh to remove larger objects. Samples of about 620 g each were packed in marinelli beaker of about 0.5 litres volume and sealed using silicon and plastic tapes for tight air free.

The samples were carefully prepared according to International Atomic Energy Agency IAEA [22] specifications for gross alpha and beta analyses, after which the samples were each contained in their planchets and were stored in desiccators waiting counting. The samples were analysed for gross alpha and beta activity using an IN-20 model gas-flow proportional counter available at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria. Each sample was counted three times and the mean used in computing the activity. The operational modes used for the counting were the α-only mode for the alpha counting and the β ($+\alpha$) mode for the beta counting. The count rate of each sample was automatically processed by the computer using the equation (1).

$$A_{(\alpha,\beta)} = B_{\alpha,\beta} \times 60/T \quad (1)$$

Where *A* (α,β) is the count rate (cpm) of alpha and beta particles, B (α,β) *is* the raw count of alpha or beta particle, T is the counting time (2700 sec. or 45 min.).

The activity of each of the samples was calculated using equation (2);

$$C_{(\alpha,\beta)} = \left(A_{(\alpha,\beta)} - G_{(\alpha,\beta)}\right) \times \frac{U_{(\alpha,\beta)}}{H_{(\alpha,\beta)} \times S_{(\alpha,\beta)} \times V} \quad (2)$$

where *C* (α,β) is the alpha and beta activity (Bq/kg), *G* (α,β) is the background count of alpha and beta particle, *U* (α,β) is the unit coefficient of alpha and beta particle (1.67×10^{-2}) conversion factor from cpm to cps (1 cps=1 Bq), *H* (α,β) is the channel efficiency for alpha or beta counting, *S* (α,β) is the sample efficiency for alpha or beta counting and V is the sample mass.

Statistical tool (correlation) was applied using Microsoft excel package 2013 which helps to measure and analyse the degree of relationship between two variables. The strength of relationship present and predictions about the variables studied can be achieved using the correlation analysis. The degree of relationship between variables is measured through the correlation analysis. The correlation analysis enable us to have an idea about the degree and direction of the relationship between the two variables in the study.The degree of relationship is expressed by coefficient which range from correlation ($-1 \leq r \geq +1$). The interpretation of the value of correlation coefficient is done with the use of square of coefficient of correlation (Coefficient of Determination r^2).

3. RESULTS AND DISCUSSION

The mean gross alpha and beta activity concentrations for soil, mineral and water samples are presented in the tables below.

3.1 Effective Dose

The annual alpha and beta effective dose due to intake of water were determined by averaging the individual annual committed effective doses contributed by the major alpha and beta emitters in the U-238 and Th-232 series of the naturally occurring radionuclides [22].

$$E_{avg}(\alpha/\beta) = \sum_i^{R(\alpha/\beta)} A_{i(\alpha/\beta)} \times DCF_{i(\alpha/\beta)} \times 730 \quad (3)$$

Where

$E_{avg(\alpha/\beta)}$ = average gross annual alpha or beta committed effective dose in the consumable water,

$A_{i(\alpha/\beta)}$= gross alpha or beta activity concentration of individual radionuclides present in the water sample and $DCF_{i(\alpha/\beta)}$= dose conversion factor for ingestion of the individual natural radionuclides for an adult taken from [9] UNSCEAR report.

A daily water intake of 2 L/day is assumed [24] thus resulting in annual consumption rate of 730 L/year.

Using the Fernandez and others [25] and Damla and others [26] procedure, it is considered that more than half of the annual dose from intake of water corresponds to radium (gross alpha radium). This was assumed in this work since the component radionuclides in the gross alpha and beta activities could not be determined due to the limited functions of the machine used. According to $Görür$ et al. [23] the major contributors to the gross β- activities are ^{210}Pb and ^{228}Ra. For calculations, the dose conversion factors of 2.80×10^{-4} mSvBq^{-1} for ^{226}Ra and 6.90×10^{-4}mSvBq^{-1} for both ^{210}Pb and ^{228}Ra, published by WHO [27] were used. The calculated effective doses are shown in Table 6.

3.2 Discussion of Results

The activity concentration of gross alpha and gross beta soil and mineral samples are given in Tables 1 and 2. The mean gross alpha and beta activities in soil and mineral samples are shown in Table 3. The mean gross alpha and beta activities in soil samples were between 4.20±2.00 Bq/kg (coal) – 11.8±4.00 Bq/kg (salt) and 739.6±542.0 Bq/kg (lead) – 1703.3±152.3 Bq/kg (limestone) respectively. These results were lower than the value of control samples collected from areas where there are no mining activities. Results for the gross alpha and gross beta activity in soil samples of mining fields are lower than those values reported by Zorer and others [28] in Van (Turkey) whose value for gross alpha and gross beta activity are 686-4713 and 73-11773 Bq/kg. The mean gross alpha activities are also lower than those reported for the surface soil and selected oil fields in Nigeria [29,30] around steel processing facility, Delta State (32.0±10.0 – 64.0±10.0 Bq/kg) and around Imiringi, Bayelsa State (530±20 Bq/kg). The mean beta activities in the present study are however within the mean value at Delta (411.5±11.5 – 2710.0±150.0 Bq/kg) but are lower than those obtained in selected oil fields around Imiringi, Bayelsa State (2929±170 Bq/kg). Gross alpha activities in soil decreased with the spread out from mining fields and much lower

comparable to the control host communities as seen in Fig. 1.

The mean gross alpha and beta activities for soil in mining fields also varies from one mineral deposition to another, with Akuana (salt mining field) and Gboko (limestone mining field) having higher activities in gross alpha and gross beta as shown in Figs. 1 and 2. This pattern of variation suggests that there is a likely contamination of the environment through the mining activities in the mineral deposition fields.

There exists a poor linear correlation between gross alpha and beta activities in the soil with 2% of the variation in the gross beta activity has been described by gross alpha activity in soil as shown in Fig. 3, thus implying that dissimilar radionuclides might be responsible for the contamination in the soil.

The mean activity in minerals samples ranged between 1.11±0.70 Bq/kg (lead), 5.20±3.00 Bq/kg (limestone) and 245.3±171.5 Bq/kg (coal) for gross alpha and beta respectively. The activities are below those values obtained from soil samples. There also exists a strong linear correlation between gross alpha and beta activities in soil and minerals (Figs. 4 and 5), with 91% of the variation in the gross alpha activity in mineral has been explained by gross

Table 1. Result of gross alpha and beta activity concentration of soil samples from mining field (Bq/kg)

Sample code	Gross alpha activity (Bq/kg)	Gross beta activity (Bq/kg)
SBRT01 BARITE	10.4±4.00	393±143.0
SBRT02	2.23±2.00	2260.0±162.0
SBRT03	5.6±3.00	825.8±157.0
SBRT04	5.57±3.00	423.3±130.0
SBRT05	1.17±2.00	392.9±137.0
SBRT06	4.42±3.00	838.5±180.0
MEAN (CONTROL)	4.90 ± 3.00 (4.2±3.00)	856.1 ±221.0 (835.0±235.0)
SLIM01 LIMESTONE	8.97±4.00	1002.0±180.0
SLIM02	13.8±4.00	748.6±149.0
SLIM03	12.8±4.00	2556.0±164.0
SLIM04	5.79±3.00	695.7±137.0
SLIM05	3.85±2.00	4455.0±156.0
SLIM06	8.61±4.00	762.5±172.0
MEAN (CONTROL)	9.0±4.00 (8.4±4.00)	1703.3±152.3 (725.0±172.0)
SLE01 LEAD	13.9±4.00	420.9±142.0
SLE02	5.74±3.00	586.3±136.0
SLE03	3.02±2.00	113.6±139.0
SLE04	6.61±3.00	717.1±156.0
SLE05	11.7±4.00	1701.0±158.0
SLE06	5.32±3.00	898.5±151.0
MEAN (CONTROL)	7.70±4.00 (3.80±2.00)	739.6±542.0 (113.0±139.0)
SCO01 COAL	5.7±3.00	586.2±136.0
SCO02	7.73±4.00	320.5±217.0
SCO03	4.38±2.00	407.6±121.0
SCO04	3.43±3.00	2594.0±180.0
SCO05	2.63±2.00	753.5±127.0
SCO06	1.34±0.00	721.7±158.0
MEAN (CONTROL)	4.20±2.00 (1.30±0.00)	897.3±84.9 (717.0±158.0)
SST01 SALT	13.6±4.00	901.3±164.0
SST02	14.00±4.00	650.9±150.0
SST03	8.93±3.00	499.8±125.0
SST04	5.92±3.00	694.8±142.0
SST05	11.9±5.00	1176.0±158.0
SST06	16.1±5.00	711.7±173.0
MEAN (CONTROL)	11.8±4.00 (8.90±3.00)	772.4±236.0 (498.8±125.0)

Table 2. Result of gross alpha and beta activity concentration of mineral samples (Bq/kg)

Sample ID	Gross alpha activity (Bq/kg)	Gross beta activity (Bq/kg)
BARITE		
MBRT01	4.42±3.00	838.5±0.00
MBRT02	1.59±0.00	1167.0±197.0
MEAN	3.00±1.00	1004.5±98.5
LIMESTONE		
MLIM01	8.61±4.00	762.5±172.0
MLIM02	1.78±3.00	1246.0±212.0
MEAN	5.2±3.00	1004.3±192.0
LEAD		
MLE01	1.05±0.20	627.1±126.0
MLE02	1.17±1.00	170.1±158.0
MEAN	1.11±0.70	398.6±142.0
COAL		
MCO01	1.37±2.00	231.2±163.0
MCO02	3.43±3.00	259.4±180.0
MEAN	2.40±1.40	245.3±171.5
SALT		
MST01	5.92±3.00	694.8±142.0
MST02	1.19±4.00	117.6±158.0
MEAN	3.56±3.30	406.2±150.0

alpha activity in soil and 80% of the variation in the gross beta activity in mineral has been described by gross beta activity in soil, which could depicts that mineral rocks are major constituent of the soil through physical weathering processes and this may suggest that similar contamination by alpha and beta particles in the mineral rocks might result in that of surface soil.

The activity concentration of gross alpha and gross beta consumable water samples are given in Table 4. The activity in water for gross alpha and beta varies between 0.0030±0.0003 – 0.0120±0.0021 Bq/L and 0.1420±0.0650 – 0.4599±0.1470 Bq/L (barite), 0.0013±0.0007 – 0.0783±0.0083 Bq/L and 0.1130±0.0120 – 1.3900±0.0111 Bq/L (lead), 0.0011±0.0027 - 0.0172±0.0069 Bq/L and 0.0344±0.0075 – 0.4060±0.3930 Bq/L (limestone) 0.0069±0.0038 – 0.3158±0.0928 Bq/L and 0.1670±0.0656 – 1.2300±0.8920Bq/L and 0.0016±0.0002 – 0.0601±0.0076Bq/L and 0.1811±0.0260 – 13.900±0.55100Bq/L (coal) respectively.

The mean activity in water samples ranged between (0.0078±0.0036 (barite) – 0.1620± 0.2530) Bq/L (salt) and 0.2200±0.0123 (limestone) – 4.8500±0.1510 Bq/L (coal) for gross alpha and beta as presented in Table 5 respectively.

The plot of mean gross alpha and beta activity in water for the sampled mining fields are shown in Figs. 6 and 7. As compared with WHO standards, the activity is below the permissible levels of 0.5 Bq/L for gross alpha in all the mining fields and 1.0 Bq/L for gross beta as stipulated by WHO [27] (except Akuana salt mining field).

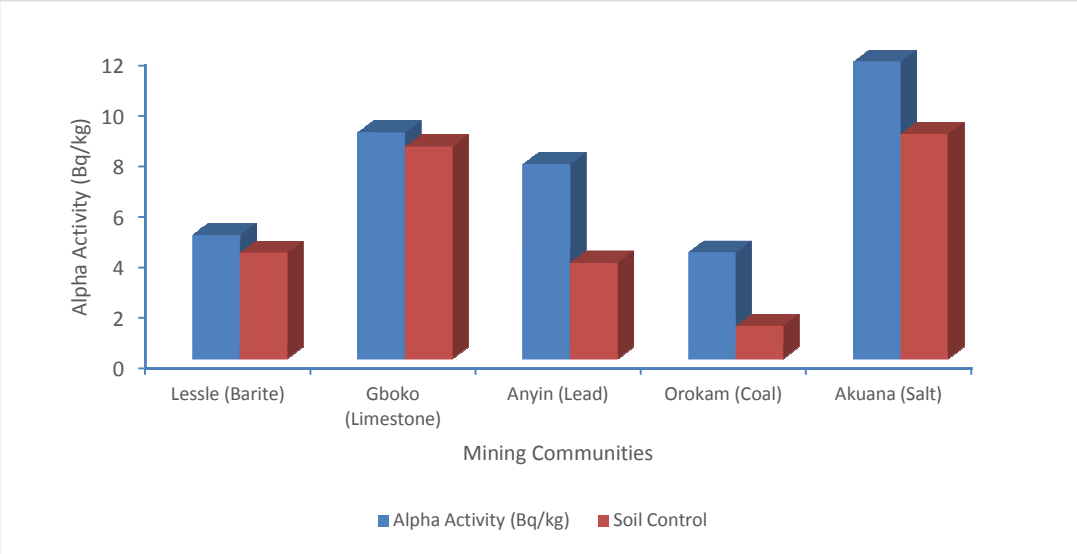

Fig. 1. Mean comparison of alpha activity with soil control (Bq/kg)

Table 3. Mean activity of gross alpha and beta in soil and mineral

Location	Soil		Mineral	
	Mean gross alpha (Bq/kg) (control)	Mean gross beta (Bq/kg) (control)	Mean gross alpha (Bq/kg)	Mean gross beta (Bq/kg)
Lessle (barite)	4.90 ± 3.00 (4.20)	856.1 ±721.00 (835.0)	3.00±1.00	1004.5±98.50
Gboko (limestone)	9.00±4.00 (8.40)	1703.3±152.30 (725.0)	5.20±3.00	1004.3±192.00
Anyin (lead)	7.70±4.00 (3.80)	739.6±542.00 (113.0)	1.11±0.70	398.6±142.00
Orokam (coal)	4.20±2.00 (1.30)	897.3±84.90 (717.0)	2.40±1.40	245.3±171.50
Akuana (salt)	11.80±4.00 (8.90)	772.4±236.00 (498.8)	3.56±3.30	406.2±150.00

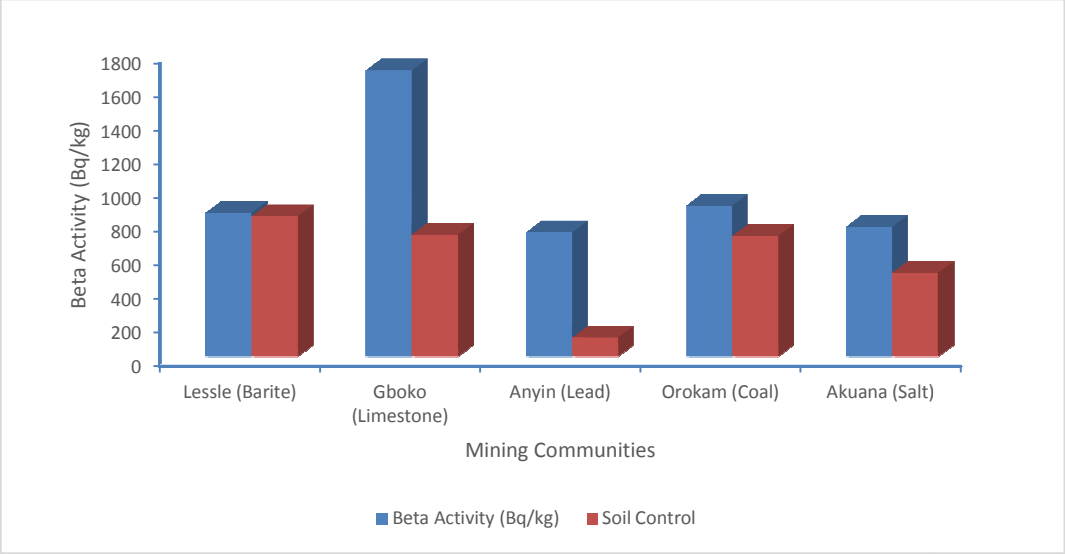

Fig. 2. Mean comparison of beta activity with soil control (Bq/kg)

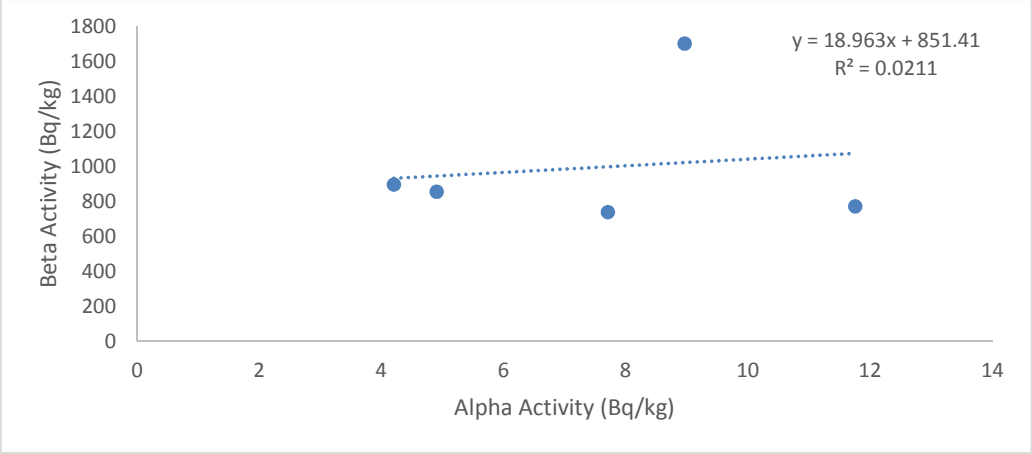

Fig. 3. Correlation of alpha and beta activity concentration in soil of the mining field

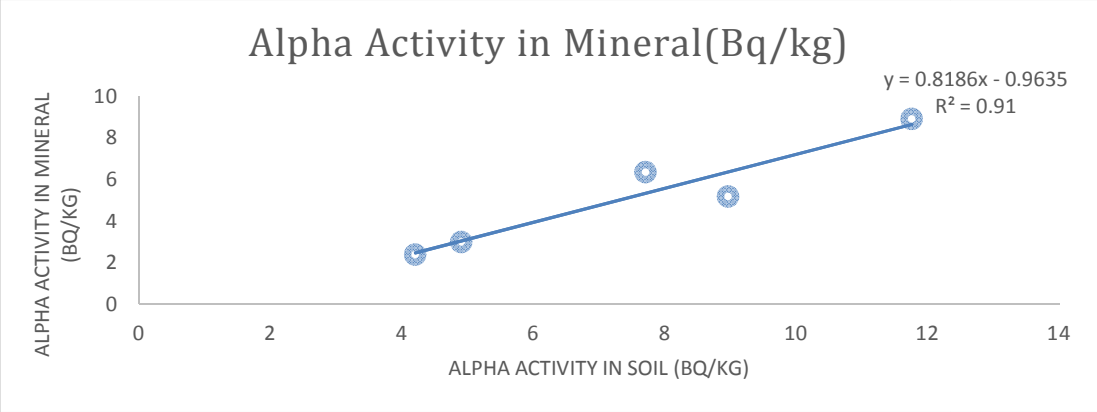

Fig. 4. Correlation between gross alpha activities in soil and mineral samples

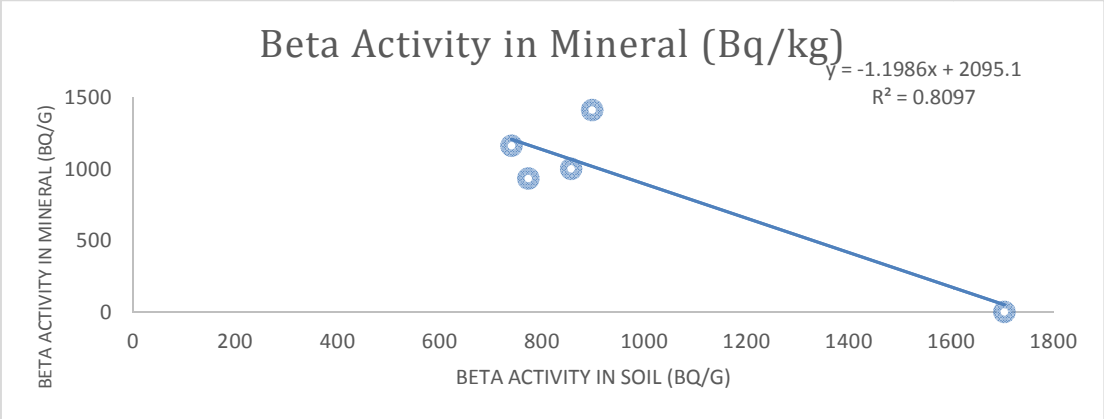

Fig. 5. Correlation between gross beta activities in soil and mineral samples

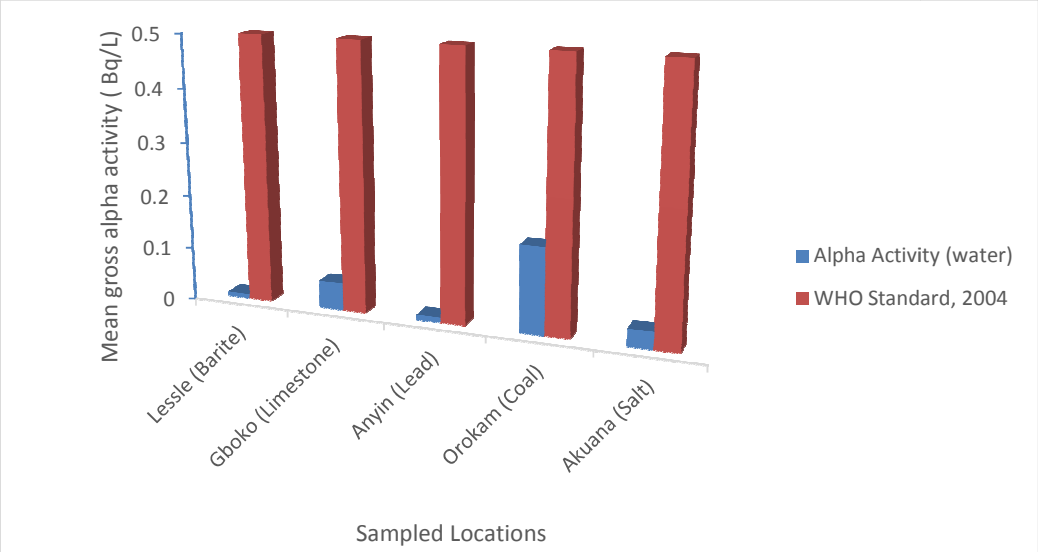

Fig. 6. Comparison of mean gross alpha activities in consumable water source from the sampled locations with standard

Table 4. Result of gross alpha and beta activity concentration (Bq/L) of consumable water samples

Sample code	Gross alpha activity (bq/l)	Gross beta activity (bq/l)
BARITE MINING FIELD		
WBRT 01	0.0030±0.0003	0.4599±0.1470
WBRT 02	0.0101±0.0047	0.2740±0.1800
WBRT 03	0.0059±0.0048	0.1810±0.0218
WBRT 04	0.0120±0.0021	0.1420±0.0650
MEAN	0.0078±0.00364	0.2640±0.153
LEAD MINING FIELD		
WLE 01	0.0013±0.0007	0.3970±0.0288
WLE 02	0.0578±0.0183	1.3900±0.0119
WLE 03	0.0783±0.0083	0.1270±0.0110
WLE 04	0.0683±0.0030	0.1130±0.0120
MEAN	0.0514±0.00833	0.5070±0.102
LIMESTONE MINING FIELD		
WLIM 01	0.0127±0.0071	0.4060±0.3930
WLIM 02	0.0068±0.0029	0.0344±0.0075
WLIM 03	0.0172±0.0069	0.1590±0.0760
WLIM 04	0.0011±0.0027	0.2790±0.0288
MEAN	0.0094±0.00742	0.2200±0.0123
SALT MINING FILED		
WST 01	0.3158±0.0928	1.2300±0.8920
WST02	0.3040±0.0782	0.1670±0.0656
WST 03	0.0201±0.0027	0.4740±0.0180
WST 04	0.0069±0.0038	0.5810±0.0218
MEAN	0.1620±0.253	0.6130±0.249
COAL MINING FIELD		
WCO 01	0.0016±0.0002	13.9±0.551
WCO 02	0.0103±0.0030	4.60±0.0147
WCO 03	0.0601±0.0076	0.7390±0.014
WCO 04	0.0593±0.0058	0.1811±0.026
MEAN	0.0328±0.00464	4.8500±0.151

Table 5. Mean activity of gross alpha and beta in water

Location	Water	
	Mean gross alpha (Bq/L)	Mean gross beta (Bq/L)
Lessle (barite)	0.0078±0.00364	0.2640±0.153
Gboko (limestone)	0.0094±0.00742	0.2200±0.0123
Anyin (lead)	0.0514±0.00833	0.5070±0.102
Orokam (coal)	0.0328±0.00464	4.8500±0.151
Akuana (salt)	0.1620±0.253	0.6130±0.249

Table 6. Effective equivalent dose in all the sampled locations

Location	Water		
	Effective equivalent dose due to radium-226 (mSv/y)	Effective equivalent dose due to beta radionuclides (mSv/y)	Total effective equivalent dose (mSv/y)
Lessle (barite)	0.0016	0.1330	0.1350
Gboko (limestone)	0.0019	0.1110	0.1120
Anyin (lead)	0.0105	0.2550	0.2660
Orokam (coal)	0.0067	2.4500	2.4500
Akuana (salt)	0.0331	0.3090	0.3420

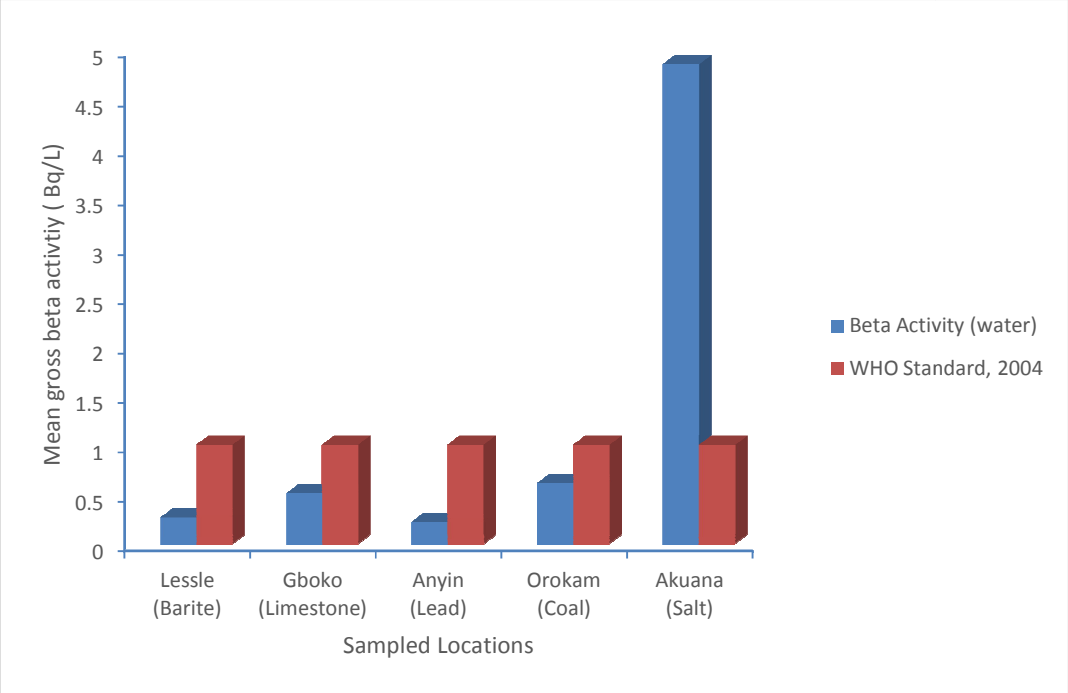

Fig. 7. Comparison of mean gross beta activities in consumable water source from the sampled locations with standard

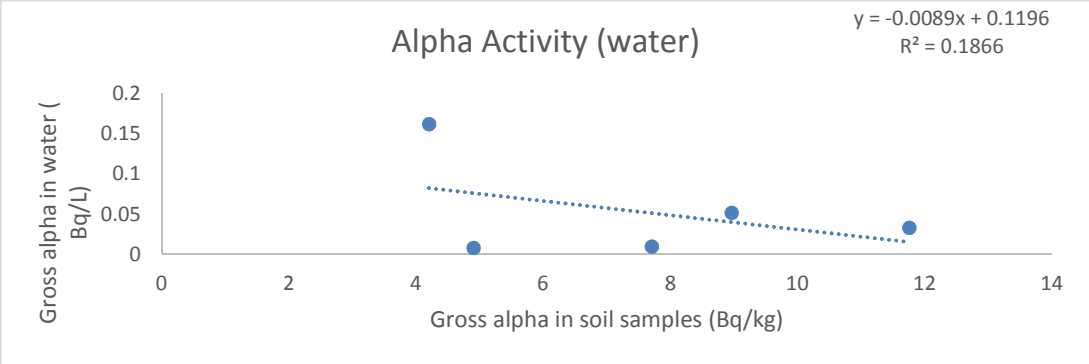

Fig. 8. Correlation between gross alpha activities in soil and water samples

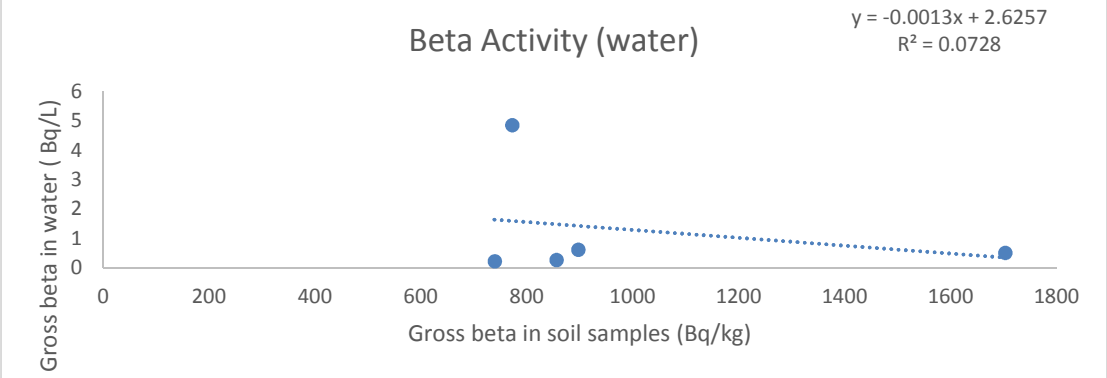

Fig. 9. Correlation between gross beta activities in soil and water samples

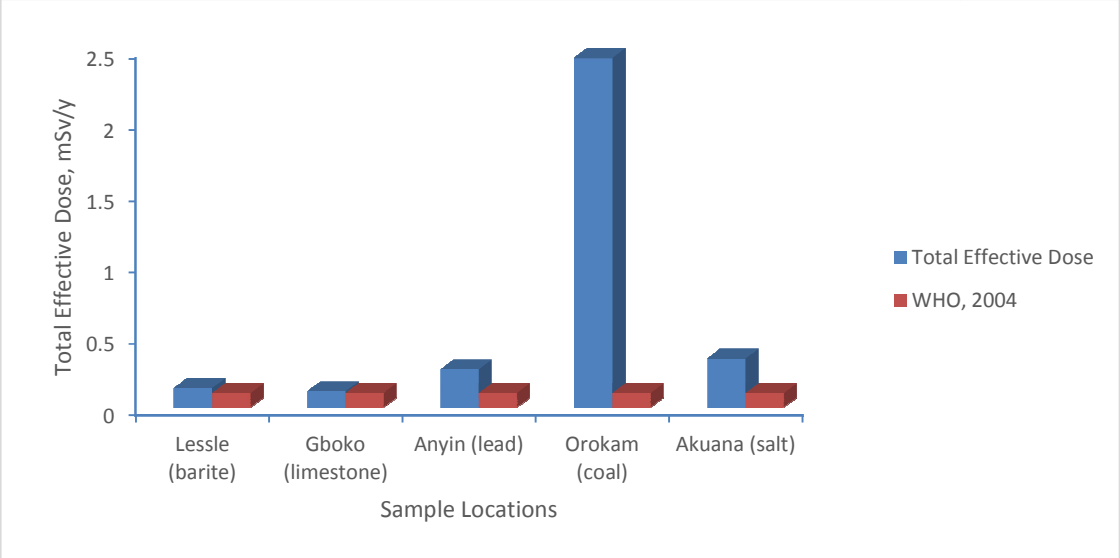

Fig. 10. Total effective equivalent dose due to alpha and beta radionuclides in drinking water

Gross alpha activities in consumable water in coal mining field was higher relative to other mineral mining field while the least activity value was obtained at the lead mining field. The gross beta activities in water decrease with different mining field where the lowest activity was obtained in lead mining fields (Anyin) and highest value of gross beta activity was obtained in salt mining fields (Akuana). The results obtained for all mining fields are within the results obtained for groundwater (well) recorded in the mining areas of Plateau State where the average activity values varies (0.010-12.590) Bq/L and (0.020-14.640) Bq/L respectively for gross alpha and beta [17]. Also, it was noted that the values in this study are lower than the results obtained for groundwater in Ado-Ekiti and Enugu State where the gross alpha and beta values reported are (0.589±0.36 Bq/L and 0.236±0.190 Bq/L) and (0.2174±0.167 and 32.105±7.441) Bq/L respectively [31,32]. 18% of the total variation in the gross alpha activity in water has been described by gross alpha activity in soil, there exists a poor linear correlation between gross alpha activities in soil and water (Fig. 8). This indicates that surface contaminant in the surrounding soil might be from exposure of mineral components of rocks from the mining activities. Thus this may not contribute meaningfully to the contamination in the consumable water. This is obvious following the pattern in gross alpha activities with the WHO standard. There also exists a weak linear correlation between gross beta activities in soil and water (Fig. 9), with 7% of the variation in the gross beta activity in water which has been described by gross beta activity in soil, indicating that consumable water contamination by beta particles might be as a result of filtration of beta-emitters nuclides leaving the soil into the groundwater. The drastic decrease in gross beta activities in most mining fields also implies that the contaminants being restricted to the source where mining activities are dominant.

The equivalent gross beta effective dose due to water intake was highest at Orokam- coal mine field and Akuana-salt mine field locations values are 2.4500 mSv and 0.3090 mSv. At Gboko (limestone mine field), the gross beta effective dose was least (0.1110 mSv). Fig. 10 shows the total effective equivalent dose due to both alpha (radium-226) and beta emitting radionuclides in consumable water. It is observed that the results in the present study areas are higher than those reported by Mazzilli, [33] for São Paulo State (Brazil) drinking water whose total committed effective dose due to consumption is 8.4×10^{-2} mSv/y which was considered to be safe. The present results are within the values reported by Agbalagba and Avwiri [34] for stream water samples, whose mean values of the effective dose for alpha emitting radionuclides are 0.354 mSv/yr, 0.707mSv/yr and 1.415 mSv/yr and the mean values of the effective dose for beta emitting radionuclides are 0.161 mSv/yr, 0.321 mSv/yr and 0.573 mSv/yr.

The total committed effective doses greatest at the coal mining field and least at the limestone mining field signify that greater risk is associated with consumable water from coal mining field and salt mining fields, compare to barite and limestone mining fields. The recommended reference dose level (RDL) of the committed effective dose of 0.1 mSv per year, [27] was not exceeded in most of the mining fields except in the coal mining fields.

4. CONCLUSION

The mean activity of gross alpha and gross beta in surface soil, mineral rock and consumable water collected from mineral mining site of Benue State, Nigeria have been determined. The result shows the variations in average activities of gross alpha and gross beta for surface soils and mineral rocks from one mineral deposition site to another. The result obtained for consumable water the average value of gross alpha and gross beta are below the World average value reported by WHO except the average gross beta activity concentration in salt mine field is quite high. The annual alpha and beta effective dose due to intake of consumable water was evaluated in order to determine the effects of the major alpha and beta emitters in water. The result indicates that consumable water from barite, limestone, salt and lead mine fields will not pose risk for workers and people living in the mining sites region. Therefore with the results obtained no potential radiological health consequence may directly be associated with the soil, mineral rock and consumable water from these mining fields. The total effective dose of consumable water in the coal mine fields is higher than the recommended level. Consumable water around the coal mine field may pose health risk as the ingested dose is quite high.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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