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Contour Maps of Gross Alpha and Beta Radioactivity Distribution in Surface Water Supply Within the Naraguta Sheet 168, Plateau State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author WEM designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors FBM and EAA managed the literature searches, analyses of the study performed and authors EEI and SPM reviewed the literature and experimental design. All authors read and approved the final manuscript.

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ABSTRACT

Formal mining started in Plateau State as far back as 1902 with Tin and Columbite as major targets. The occurrence of these minerals brought about intense mining activities in the state. The early growth and development of the areas covered by the Naraguta Topographical Sheet 168 are closely related to commercial tin mining activities in the area and Plateau State at large. This has left behind a post mining environment scattered by numerous mine ponds and dams surrounded by heaps of mine spoils (dumps/overburden), mine tailings containing radioactive minerals that are washed in the water supply and a devastated landscape. A survey of gross alpha and beta radioactivity in Surface water supply from tin mining areas of Plateau State was carried out. Forty eight (48) Surface water samples (25 mine ponds and 23 streams) were drawn randomly. Each

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sample was drawn in two litres plastic container and about 10 ml of Nitric acid was immediately added for preservation and to avoid adsorption of radionuclides onto the walls of the containers. The samples were later evaporated to dryness and the residues were transferred into Planchets. They were then counted for gross alpha and beta activity using a Proportional Counter (MPC-2000-DP). The results obtained showed that the range of alpha activity varied from (0.05±0.01–6.64±0.03)Bq/l with a geometric mean of 0.41Bq/l for mine pond samples and (0.14±0.01–4.310±0.01)Bq/l with a geometric mean of 0.64Bq/l for stream water samples. While the range of beta activity varied between (0.01±0.001–6.68±0.04)Bq/l with geometric mean of 0.14Bq/l and (0.04±0.01-1.17±0.02)Bq/l with geometric mean of 0.25Bq/l for mine ponds and stream water samples respectively. The experimental results obtained show that gross alpha and gross beta activities in most locations of surface water are above the World Health Organization recommended guideline value of 0.5Bq/L for alpha activity and 1.0Bq/L for beta activity. This may constitute radiological hazards to the consumers of the water over a long period of time. Superimposing the contour maps of activity concentrations over the geology of the area showed higher activities within the Younger Granites areas compared to the Basement rocks and the Newer Basalts.

Keywords: Tin mining; gross alpha activity; gross beta activity; surface water.

1. INTRODUCTION

Water is the most abundant substance on earth and it's the principal constituent of all living things. It is generally obtained from two principal sources: surface water such as lakes, rivers, streams, ponds etc and groundwater such as borehole and well water [1]. Water is a tasteless, odorless liquid at ambient temperature and pressure and appears colorless in small quantities, although it has its own intrinsic very light blue hue. It is a very strong solvent, dissolving many substances: both substances that mix well with water and dissolve easily and those that do not mix well and dissolves sparingly. Water is important and necessary for life. All organisms need water, some live in it and some drink it.

Man uses water for many purposes such as thermal transfer agent, power generation, agriculture, domestic use, food processing, and recreation and as a solvent [2]. Water has to be skillfully managed and kept pure if it must be used for these diverse purposes. Plant and animals require water that is moderately pure and they cannot survive if the water is loaded with toxic chemicals or harmful micro-organisms [3].

In nature however, water washes gases from the atmosphere, dissolving minerals and soluble substances from the soil through which it flows. As such, many contaminants and micro-organisms enter into it thereby contaminating the water. Water can also be polluted by the waste of civilization which enters it through the discharge of water-borne wastes. Both anthropogenic pressures and natural processes account for degradation in surface water [4]. Activities associated with tin mining and mineral processing operations have significant potential to pollute both surface water and groundwater directly or indirectly. Mining by its nature consumes, diverts and can pollute water resources [5].

In Plateau State, particularly the areas within the Naraguta topographical sheet 168 where open pit and underground workings for tin and columbite took place, contamination of surface water and groundwater have been experienced within the communities [6]. Exposure to natural radiation emitted by radioactive minerals is a major source of health hazards. The radiation intensity increases when the minerals are concentrated. It has been established that some minerals such as Monazite, Pyrochlore and Xenotime, which are obtained as product of tin mining in Jos Plateau State are radioactive [7]. Because of lack of market, most of these minerals which were in the form of concentrate or tailings were abandoned in many previous mining sites on the Plateau. Some of these sites had mining communities which developed into villages where high levels of radiations have been recorded [8].

The occurrence of natural alpha and beta emitting radionuclides in drinking water poses health hazards when these radionuclides are taken into the body by ingestion. Radionuclides in drinking water can cause human internal exposure when they are incorporated as part of the human food chain [9].

The objective of this research is to determine the levels of gross alpha and beta radioactivity concentration in surface water (mine ponds and streams) within the tin mining areas of Plateau state and to examine the impacts of mining and the geology of the area on water quality by correlating these gross alpha and beta activity levels with the geology.

2. MATERIALS AND METHODS

2.1 Study Area

The study took place majorly in some communities of Local government areas within the Naraguta topographical sheet 168 such as Jos North, Jos South, Barkin-Ladi, and Riyom LGAs of Plateau State. Mining is a very common practice in and around the communities in many forms like artisanal mining, surface mining, deep shaft mining and alluvial mining.

2.2 Geology of the Study Area

The study area is underlain by three main classes of rocks. These include the Basement Complex, the Younger Granites and the Newer Basalts. The Basement rocks are generally confined to the western and southern parts of the topographical sheet, the Younger Granites are mainly found stretching from the South-Eastern to the Northern part of the area. The Newer basalts rocks are found mainly around the Southern parts with few pockets in the Central and in the North-Western parts as shown in Fig 1. Among the three rock types, the Younger Granites are known to contain higher quantities of associated radioactive minerals such as Zircon, Thorite, Monazite and trace amounts of Xenotime [10]. These minerals could be washed into the surface water and thereby causing radiological contamination of the Surface water sources.

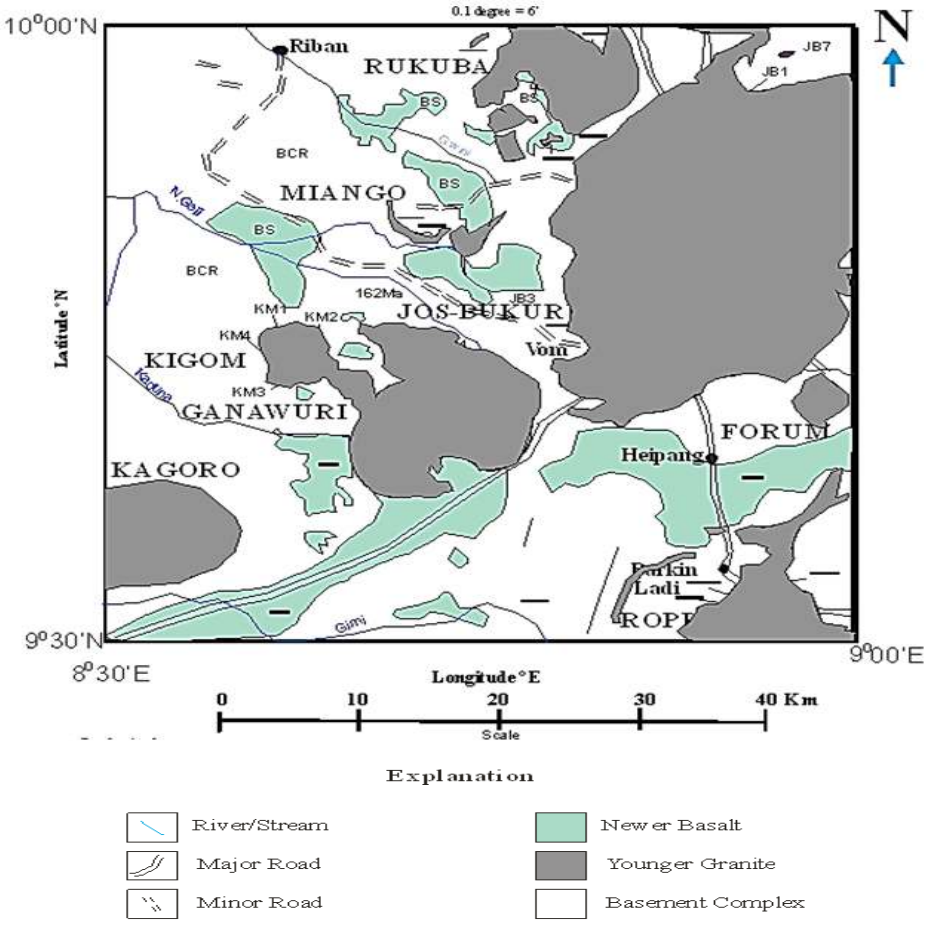

Fig. 1. Geological map of Naraguta Area, sheet 168
Geological map modified after [11]

The area is bounded between Longitude 8°30' 00.00"E to 9°00' 00.00" E and Latitude 9°30' 00.00"N to 10°00' 00.00" N.

2.3 Materials

The equipment used for the gross alpha and beta radioactivity measurement in water samples included: MPC 2000 DP (Monitor Proportional Counter), Electric hot plates, Beakers (Pyrex), 2L plastic containers, Drying oven, Drying lamp, Graduated cylinders, measuring cylinders of capacity 1000cm^3, Porcelain dish of capacity 50ml, Stainless steel Counting Planchets (3 cm), Analytical balance, Gloves, Plastic containers, Masking tape, Blur forceps and Map (Naraguta sheet 168).

2.4 Methods

2.4.1 Sampling procedure and preparation

The field data collection was carried out in the month of March/April and it lasted for about two weeks. The month of March was chosen because it represents the peak of the dry season in the study area. This is the time when water quality determination is critical; no flow of one source into another and good accessibility is enhanced. Water samples were collected from Surface water sources (mine ponds and streams) in Plateau State within Naraguta Topographical Sheet 168.

The sampling technique that was used for this work was the stratified random sampling. This technique was more important than others in this work because it ensured that all groups (sources) were adequately represented in the sampled population or area. Forty eight (48) water samples from public water supply (consisting of 25 mine pond samples and 23 stream samples) were collected from communities affected by tin mining. Control sample was taken from a community with no history of tin mining but with similar geographical features to the study areas. From each sampling point, 2 liters of the water samples were collected from each mine pond and stream source in two liter plastic containers with about 1% air space left for thermal expansion. Containers were rinsed twice with the samples being collected to reduce contamination by the original content of the sample container.

The samples were immediately acidified with nitric acid solution to reduce the pH, minimized precipitation, adsorption or absorption by the walls of the container and to prevent the growth of micro-organisms [12]. The samples were air tight and were taken to the laboratory and held for about one month as the maximum holding period before evaporation [13].

In this work, the ISO9696 (alpha) and ISO9697 (beta) methods were used for the detection and measurement of alpha and beta radioactivity in drinking water because of their high sensitivity and efficiency [13]. Out of the two liters of each samples collected, one liter was evaporated to reduced volume of 100 to 50 ml. It was transferred into a weight porcelain dish (w_1) of 150 ml and placed under an infra-red lamp until it was completely dried. It was left to cool under normal condition and weighed as (w_2). The weight of the porcelain dish was subtracted from (w_2) to obtain the weight of the residue (w_s) in milligrams. If the weight of the residue was greater than the required residue, then only the required residue size was taken into a weighted counting Planchet. The mass of the residue was about 0.077g which was obtained based on the fact that ISO-standard requires that, about 0.1 g of the residue should be placed in the Planchet for alpha and beta radioactivity counting. Vinyl acetate was added into the sample residue to make them stick to the Planchet to prevent scattering of the residue during counting. Each sample was counted using MPC-2000-DP for 45 minutes for a minimum of 3 cycles and the average result taken.

2.5 Calibration of the Detector

The alpha standard used was ^{232}Pu with a half-life of 24110 years while the beta standard was ^{90}Sr with half-life of 28 years. Their respective activities were calculated at the time of the calibration. The identification serial numbers of the sources are EBSB20/50056 and EBSB20/14539 respectively. These standards were certified by CERCA LEA laboratories in France with certification numbers CT001/1285/0019920 – 1927 and CT1271/00/1778 – 11783, respectively. The plateau test was run with the manufacturer's calibration standards (^{232}Pu and ^{90}Sr) whose activities ranges from 133.29 to 185.51 Bq and 92.31 to 1103.68Bq respectively in all the three operating modes. This test was run for 1800s for five cycles. The operational efficiencies of the channels of the counter were obtained as shown by [14].

2.6 Gross Alpha and Beta Analysis

The gross alpha and beta radioactivity counting equipment used in this research work was the low background system MPC-200-DP Proportional counter available at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria. The sample loader of the equipment is designed to require the least effort and range of motion from users. It also gives clear, unambiguous feedback to show that it is opened or closed.

The MPC-2000-DP contains a custom designed detector with Zinc Sulphide layer bonded to a plastic scintillator. This combination is optically coupled to a photo-multiplier tube (PMT). The outermost layer detects alpha particles and the inner layer detects beta particles.

The activity concentration C, in Becquerel per Litre, of the solution is calculated from the equation

$$C = R_n \times \frac{1}{\epsilon_s} \times \frac{1}{V_p} \quad (1)\ [15]$$

Where

C is the activity in Becquerel per Liter

R_n is the sample count rate per second, corrected for background counts

ϵ_s is the fractional efficiency of counting the radioactive standard

V_p is the volume of sample in litres equivalent to the mass on the planchette

Thus $R_n = R_b - R_0$

R_b is the observed sample count rate, in pulses per second

R_0 is the background planchette count rate in pulses per second

$$\epsilon_s = \frac{R_s - R_0}{0.1A \times 14.4} \times 1000 \quad (2)$$

Where

R_s is the observed standard rate, in pulse per second

A is the area of the Planchette, in square millimeters

0.1A is the mass of the standard solid (potassium chloride solid) in milligram, on the Planchette.

The activity of ^{40}K in potassium chloride is 14.4/1000 Bq.g^{-1}. One Becquerel is One disintegration per second.

$$V_p = \frac{V}{m} \times 0.1A \quad (3)$$

Where

V– is the volume of sample, in litres

m – is the mass, in milligrams of ignited residue from volume V.

Thus, the equation for the activity concentration becomes [13]

$$C = \frac{(R_b - R_0) \times 0.1A \times 14.4 \times m}{(R_s \times R_0) \times 1000 \times V \times 0.1A}$$

$$C = \frac{(R_b - R_0) \times 14.4 \times m}{(R_s \times R_0) \times 1000 \times V} \quad (4)$$

The final activity equation for C, in Becquerels per Litre, then becomes

$$C = \frac{(R_b - R_0) \times 14.4 \times m \times 1.02}{(R_s \times R_0) \times 1000 \times V} \quad (5)$$

It is important that the factor 1.02 be included in the final equation to correct for the 10 ml of the nitric acid added to the sample as a stabilizer. The standard deviation S_c associated with the activity of the sample corrected for background is calculated as follows

$$S_c = \sqrt{\frac{R_b}{t_b} + \frac{R_0}{t_0}} \times \frac{14.4 \times m \times 1.02}{(R_s \times R_0) \times 1000 \times V} \quad (6)$$

Where t_b and t_o are the durations of the counts of the sample and background respectively.

3. RESULTS AND DISCUSSION

3.1 Gross Alpha / Beta Radioactivity Analysis in Samples from Different Sources and Locations

Tables 1 and 2 show the Gross Alpha and Beta activity concentration levels in mine ponds and stream water samples in the study area.

Figs. 2 and 3 Shows the contour maps of the gross alpha and beta activity levels in surface water in the area.

Table 1. Gross Alpha and Beta radioactivity concentration (Bq/L) of Pond water samples collected in mining areas in Plateau State

Sample ID	Sample location	Elevation (m)	Geographical coordinate	Alpha(α) activity (Bq/L)	Beta(β) activity (Bq/L)
PW01	Ratatis (Dorowa)	1321	N09º30'52.2" 0.490±0.013 E008º59'51.6"	0.49±0.01	0.09±0.002
PWO2	Kari	1302	N09º30'59.3" E008º59'57.8"	0.72±0.02	0.62±0.02
PW03	SabonLayi B/Ladi	1320	N09º31'46.0" E008º53'27.5"	0.14±0.01	0.02±0.01
PW04	Police barrack B/Ladi	1319	N09º33'02.4" E008º53'41.8"	0.18±0.01	0.68±0.01
PW05	Workshop B/Ladi	1313	N09º32'48.2" E008º53'32.1"	0.05±0.01	0.02±0.01
PW06	Sho road	1320	N09º32'28.0" E008º53'05.1"	0.56±0.01	0.01±0.003
PW07	Rim	1202	N09º34'22.8" E008º44'58.4"	0.36±0.02	0.14±0.01
PW08	RahwolGassa	1293	N09º34'26.2" E008º53'51.0"	0.21±0.01	0.07±0.01
PW09	Heipang	1269	N09º40'10.4" E008º53'17.1"	0.44±0.01	0.29±0.02
PW10	Foron Zabot	1241	N09º41'09.8" E008º51'25.4"	0.200±0.01	0.01±0.001
PW11	Jantar Kuru	1290	N09º41'30.5" E008º51'25.4	0.42±0.02	0.24±0.02
PW12	Bisichi	1290	N09º42'43.1" E008º54'30.5"	6.64±0.03	6.68±0.04
PW13	Angul dee	1275	N09º44'59.4" E008º51'26.7"	0.50±0.01	0.01±0.009
PW14	Zawan	1281	N09º46'18.9" E008º52'10.4"	0.15±0.011	0.07±0.01
PW15	Mai-idon-Taro	1186	N09º42'55.4" E008º58'52.5"	0.34±0.02	0.11±0.01
PW16	Mai-idon-Taro B.	1192	N09º44'57.3" E008º59'36.2"	1.23±0.02	1.13±0.02
PW17	Sot-Gyel	1242	N09º47'10.6" E008º50'16.6"	2.66±0.02	0.25±0.02
PW18	Sabon Gidan Kanar	1202	N09º47'16.8" E008º48'57.9"	0.62±0.02	0.06±0.01
PW19	Vom	1320	N09º42'13.8" E008º46'08.6"	0.23±0.01	0.01±0.009
PW20	Kwan	1335	N09º50'28.6" E008º55'27.0"	0.24±0.01	0.38±0.04
PW21	Doi-Du I	1339	N09º49'44.9" E008º55'03.0"	0.61±0.03	0.41±0.01
PW22	Doi-Du II	1303	N09º48'42.0" E008º55'00.2"	0.53±0.02	0.34±0.01
PW23	Gura-Topp	1329	N09º49'06.9" E008º54'12.8"	0.48±0.01	0.29±0.01
PW24	TCNN	1316	N09º48'03.9" E008º53'29.2"	0.36±0.01	0.52±0.01
PW25	Rayfield resort	1330	N09º50'47.9" E008º54'56.9"	0.29±0.09	0.07±0.01
Control	Daika	NA	NA	NA	NA

PW: Pond Water

Table 2. Gross Alpha and Beta radioactivity concentration (Bq/L) of streams water samples collected in mining areas in Plateau state

Sample ID	Sample location	Elevation (m)	Geographical coordinate	Alpha(α) activity (Bq/L)	Beta(β) activity (Bq/L)
SW01	Ratatis (Dorowa)	1286	N09º31'48.6" E008º59'14.0"	0.79±0.01	0.33±0.01
SW02	Nafan Dredge	1232	N09º34'46.2" E008º59'01.5"	1.54±0.01	1.17±0.02
SW03	Ropp	1302	N09º31'57.9" E008º57'08.2"	1.04±0.01	0.60±0.02
SW04	BarakinLadi	1315	N09º32.05'5" E008º55'08.3"	0.43±0.01	0.25±0.01
SW05	Sho	1296	N09º32'11.3" E008º51'02.1"	0.55±0.01	0.10±0.01
SW06	RahwolGassa	1280	N09º34'55.2" E008º54'10.2"	1.26±0.02	0.83±0.02
SW07	Heipang	1264	N09º39'19.7" E008º53'21.9"	0.18±0.01	0.04±0.001
SW08	ForonZabot	1236	N09º41'09.7" E008º57'07.2"	0.62±0.02	1.17±0.02
SW09	Bisichi	1247	N09º42'29.2" E008º54'51.7"	4.31±0.01	0.50±0.01
SW10	JantarKuru	1258	N09º41.43.1" E008º53'09.3"	0.62±0.02	0.23±0.01
SW11	MarabaJama'a	1279	N09º43.22.5" E008º51'53.6"	1.13±0.01	0.39±0.05
SW12	Rim	1196	N09º35'24.9" E008º45'24.2"	0.49±0.01	0.09±0.003
SW13	Hoss	1220	N09º37'09.8" E008º43'33.6"	0.27±0.01	0.04±0.001
SW14	River Kaduna	936	N09º40'01.8" E008º37'48.8"	1.02±0.01	0.56±0.01
SW15	Vom	1333	N09º41'56.4" E008º42'33.1"	0.14±0.01	0.04±0.001
SW16	Angul Dee	1242	N09º47'01.5" E008º51'26.1"	0.58±0.01	0.18±0.01
SW17	DU	1299	N09º46'52.9" E008º53'01.4"	0.37±0.02	0.27±0.02
SW18	Gyel	1242	N09º47'12.5" E008º50'24.8"	0.66±.0.15	0.40±0.02
SW19	Sot-Gyel	1242	N09º47'12.5" E008º50'24.8"	0.87±0.01	0.38±0.01
SW20	Rayfield	1304	N09º49'50.2" E008º54'10.9"	0.33±0.01	0.22±0.003
SW21	Gura-Zot	1306	N09º51'48.0" E008º55'43.2"	0.27±0.01	0.04±0.01
SW22	British American Junction	1241	N09º53'56.0" E008º53'36.9"	2.13±0.05	1.12±0.02
SW23	Tina Junction	1235	N09º54'42.2" E008º54'44.6"	0.66±0.02	0.25±0.02
Control	Daika	1113	N09º28'01.1" E009º10'29.3"	0.003±0.001	0.01±0.002

SW: Stream Water

Tables 1 and 2 show sample locations, gross alpha and beta radioactivity concentration levels of the sources. The results in the tables show that the alpha activities measured are in the range of 0.05±0.01-6.64±0.03 Bq/l and 0.14±0.01-2.13±0.05 Bq/l for mine ponds and streams respectively. The beta activities range from 0.01±0.001–6.68±0.04 Bq/l and 0.04±0.001–1.17±0.02 Bq/l for the same sources respectively. The geometric mean for alpha activities were 0.41±0.02 Bq/l and 0.64±0.02 Bq/l while that of beta activities are 0.13±0.01 Bq/l and 0.25±0.01 Bq/l for the mine ponds and streams respectively. The errors quoted in the Tables 1 and 2 represent the standard deviation from repetition of measurements. The control water samples from Daika, a non –tin bearing community in Panyam District of Mangu LGA in Plateau State had alpha activity of 0.003±0.001 and beta activity of 0.01±0.002 for stream. Control values for mine ponds are not shown because there are no mine ponds in the control area.

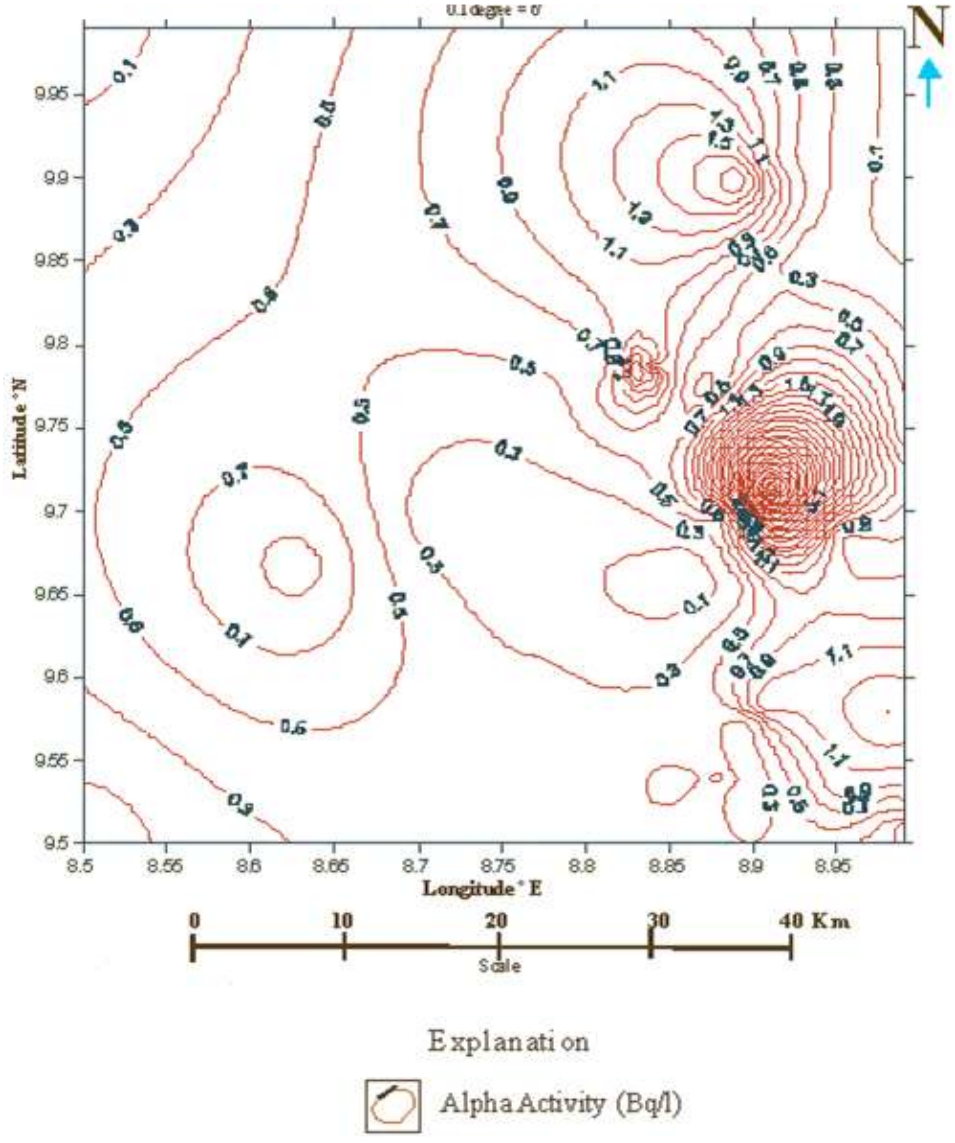

Fig. 2. Distribution of Alpha (α) activity in surface water within the Naraguta Sheet 168

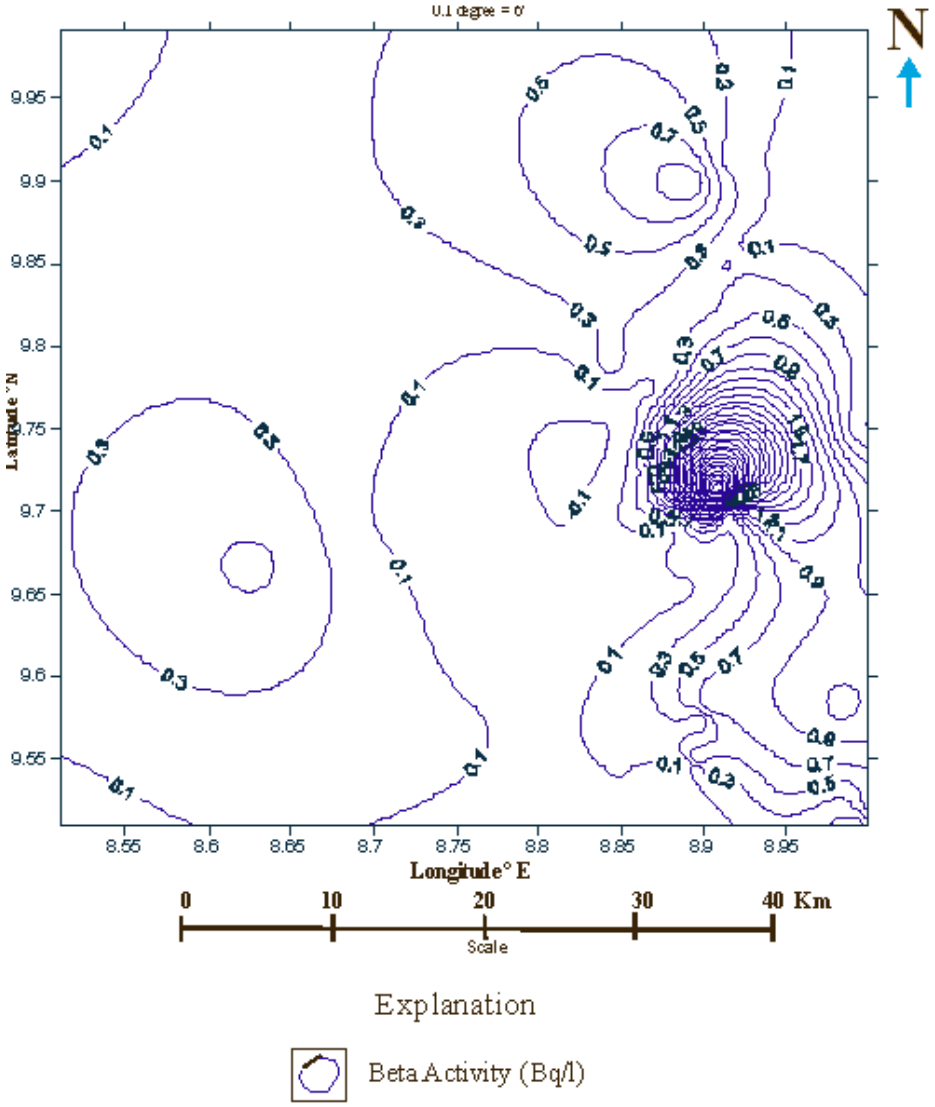

Fig. 3. Distribution of Beta (β) activity in surface water within the Naraguta sheet 168

The contour map in Fig. 2 represents the gross alpha activity distribution in surface water(mine ponds and streams) within the Naraguta sheet 168. Dense contour lines show generally high activity values. The areas bounded by latitudes 9.67^0-9.80^0, and longitudes 8.86º-8.99º, have elevated concentration levels. Fig. 3 shows the distribution of beta activity in surface water within the Naraguta sheet 168. The areas bounded by latitudes 9.70º-9.80ºN, and longitudes 8.85º-8.98ºE, signify areas of elevated beta concentrations, with values ranging from 1.13±0.02 Bq/l to 6.68±0.04 and 1.12±0.02 Bq/l to 1.17±0.02 Bq/l. Some of the specific areas are Nafan dredge, Foron Zabbot, Bisichi, Mai-idontaro, and British American Junction.

The high alpha values for mine ponds and streams ranged from 1.50±0.01 Bq/L to 6.64±0.03 Bq/l and 0.55±0.01 Bq/l to 2.13±0.05 Bq/l. Some specific areas of high concentration levels are Bisichi, Sho, Mai-idon-toro, Sabongidankanar, Doi, Nafan Dredge, Ropp, Maraban Ja'ama, Sot Gyel and British American Junction. These areas show activity concentrations above the World Health Organization recommended levels of 0.5 Bq/l and 1.0 Bq/l for alpha and beta activities in drinking water (WHO, 2008).

Figs. 4 and 5 Show the superimposed radioactivity contour maps on the geology of the study area Figs. 4 and 5 show the activity

distributions in relation to the geology of the study area. By superimposition of the contour map of distribution of alpha and beta activities over the geology of the area, it can be seen that the activity concentrations are higher within the Younger Granites compared to the Basement rocks and the Newer Basalts. It can observed that the gross alpha and beta activities are higher within the Jos-Bukuru, Forum and Ropp complexes and especially around Forum complex. These Younger Granite Complexes are known to be associated with significant deposits of Cassiterite (tin oxide, SnO_2) and Columbite (Oxide of Tantalium-niobium, iron and manganese, (Fe, Mn) (Ta, $Nb)_2O_6$), as well as radioactive mineral residues such as thorite ($ThSiO_4$), Zircon ($ZiSiO_4$) and Monazitee (Ce, La, Yt)PO_4) [16,17]. Within the Forum and environs many rivers and mine ponds can be seen all over the area. They are used for processing Cassiterite and Columbite and therefore water from surface sources in the area will normally have elevated values of alpha and beta activity compared to surface water from other complexes.

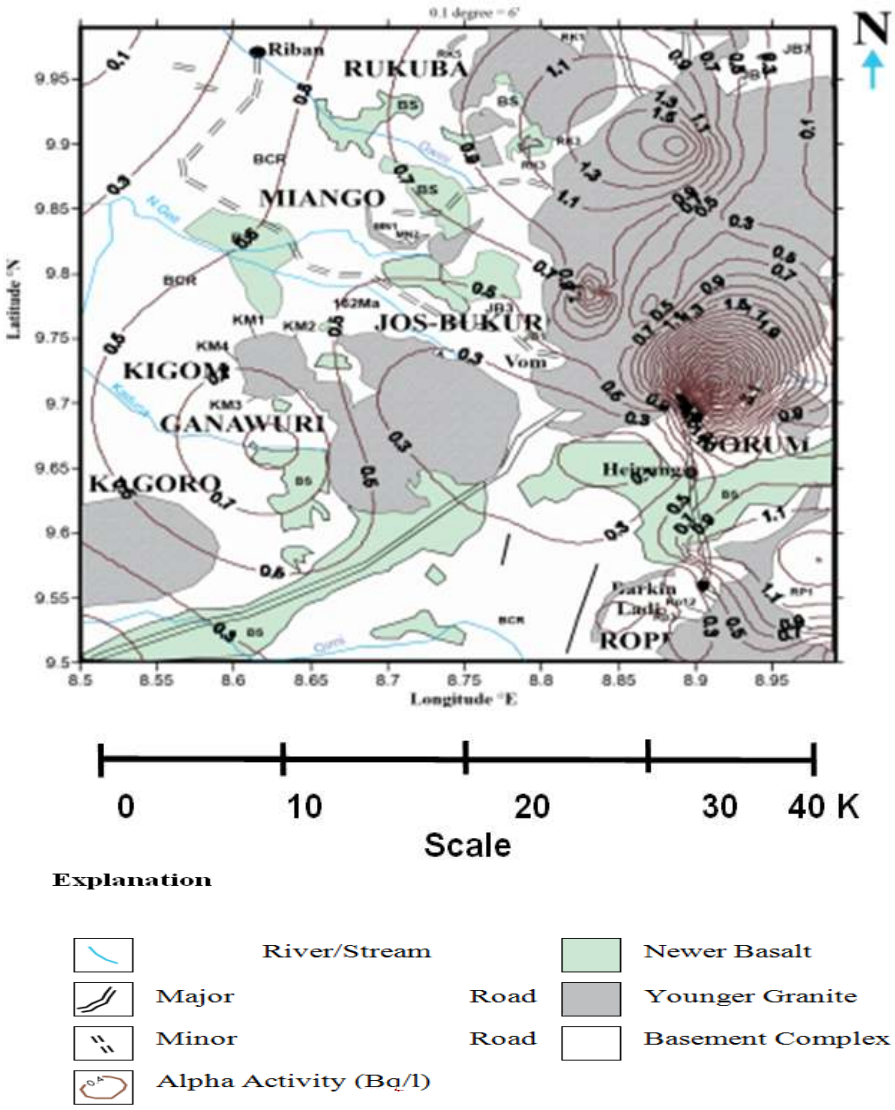

Fig. 4. Geology and distribution of alpha (α) activity in surface water within the Naraguta sheet 168

Geological map modified after [11]

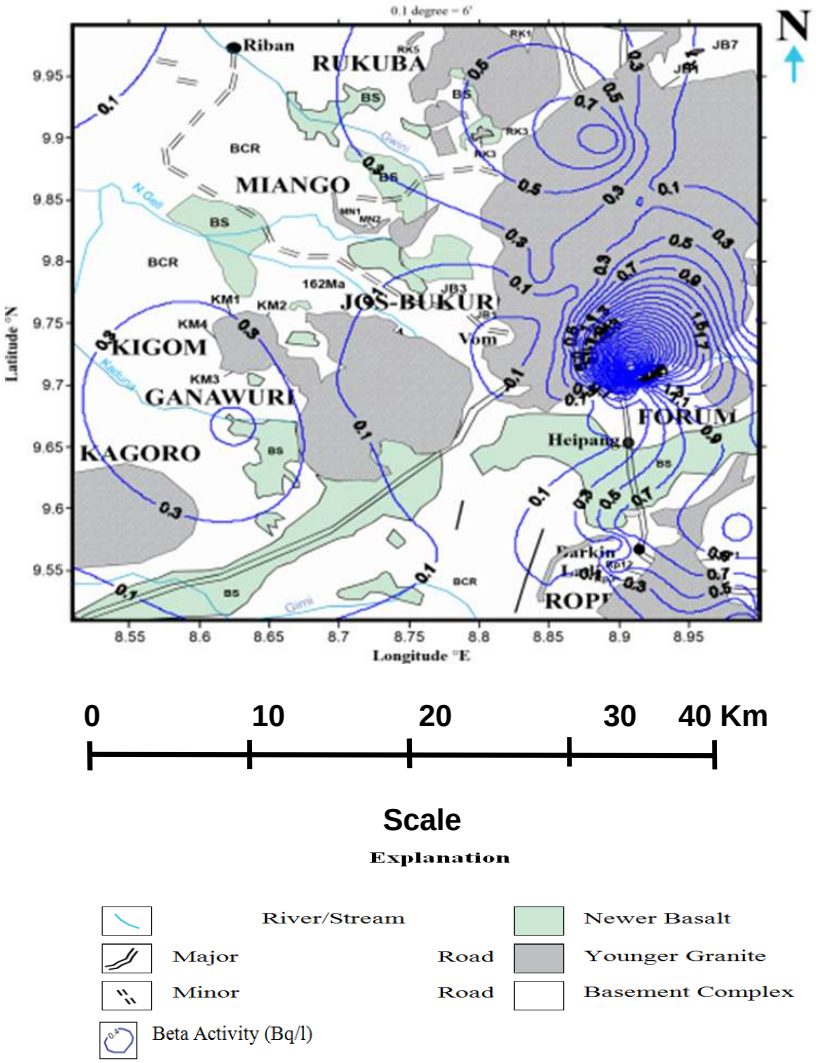

Fig. 5. Geology and distribution of beta (β) activity in surface water within the Naraguta sheet 168

Geological map modified after [11]

High radiation values in these areas may be attributed to enrichment of radioactive elements within the granites that essentially constitute these complexes [18] The radionuclides includes Cesium (Cs), Thorium (Th), Scandium (Sc), Rubidium (Rb), Zirconium (Zr), Stratium (Sr) among others.

Indiscriminate disposal of radioactive mine wastes into the environment also constitutes radiological problem in the area of study. These mine wastes are rich in Zircon, Monazites, and Xenotime. Activity concentration of between 3600 – 188000 Bq/Kg is now known to exist in some places within these areas [10]. Mean activity concentration of K- 40, Ra – 226 and Th – 232 have also been given to be 1251.7±478.3 Bq/Kg, 38.67.7±1282.7 Bq/kg and 8301.9±2862 Bq/Kg respectively as against a value of 447.0±68.0 Bq/Kg, 37.4±7.4 Bq/kg and 115.4±16.7 Bq/kg for normal or no mineral processing areas for the same radionuclides [19]. It can be seen therefore that radiation values from mining and mineral processing sites are quite high

4. CONCLUSION

Base on the findings from this research work, conclusions can be drawn as regards the levels

of alpha and beta radioactivity in surface water supply within the Naraguta Sheet 168 located on the Jos Plateau. The presence of ionizing radiation has been established in surface water from the study area. The research reveals that the levels of gross alpha and beta activity varied widely within the mining areas from one mine pond or stream to the other. The relatively high activity above the WHO recommended standard of 0.5 Bq/l for alpha and 1.0 Bq/l for beta activity [20] are probably attributed to the impact of tin mining activities on the environment. This could result from the contamination of surface water. The uncontrolled disposal of mine tailings into the environment has also affected the surface water supply which is used for irrigation as well as drinking water for humans and animals. Therefore it may be concluded that water quality from some mine ponds and streams in the study area have been degraded. Prolonged internal exposure to these levels of radioactivity through water ingestion from these sources, agricultural products and recreational activities may pose radiological hazards. It is recommended that drinking water from these sources should be treated by reversed osmosis or ion exchange methods which can help remove the radionuclides.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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