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Gross Alpha and Beta Activity Concentrations in Surface Water Supplies from Mining Areas of Plateau State, Nigeria and Estimation of Infants and Adults Annual Committed Effective Dose

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Authors' contributions

This work was carried out in collaboration between all authors. Author WEM designed the research work, wrote the protocol, wrote the first draft of the manuscript and collected the data. Author SOA. wrote the geology of the study area, authors DLC and RAO managed the literature searchs and analysed the data, authors EEI and SPM reviewed the literature and the experimental design. All authors read and approved the final manuscript.

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ABSTRACT

A radiological characteristic of surface waters of the mining areas of Plateau State, Nigeria covered by the Naraguta Topographical sheet 168 was carried out in the month of March 2012. For this purpose forty – eight (48) surface water samples were collected from 25 mine ponds and 23 streams. Analysis included gross alpha and gross beta activities using MPC – 2000 – DP and estimation of committed effective Dose to the different age groups of the general public. The results obtained showed that the gross alpha activities ranged from (0.047±0.010 – 6.640±0.032)Bq/l with a geometric mean of 0.410±0.016Bq/l for mine ponds samples while the

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gross beta activities for mine ponds ranged from (0.001±0.009-6.680±0.039)Bq/l with a geometric mean of 0.125±0.010Bq/l. Also the gross alpha activities for stream water samples ranged from (0.140±0.011 – 4.310±0.013)Bq/l with a geometric mean of 0.642 ±0.015Bq/l and the gross beta activities for stream samples ranged from (0.040±0.001 – 1.170±0.018)Bq/l with a geometric mean of 0.250±0.008Bq/l. The annual committed effective dose for all age groups was calculated and they showed elevated values above the ICRP acceptable standard of 0.1mSv/yr. This implies that infants and children who are more susceptible to radiation dose through water ingestion may be exposed to high radiation health risk.

Keywords: Gross alpha; gross beta; mining areas; committed effective dose; mine ponds; streams.

1. INTRODUCTION

Natural occurring radioactive materials (NORM) are frequently found in surface water supplies in Plateau state as a result of the natural geology and the mechanized tin mining activities that had taken place in the area [7]. Tin mining has a very long history in the Jos Plateau. It started in 1904 and by the mid-1920s more cassiterites(tin ores) discoveries had been made which resulted in more mechanized extraction techniques to meet the high demands in tin by 1960s – 1970s. This in turn results in high generation of radioactive wastes (tailings) [5]. When the demand in tin gradually declined in the late 1980s, it led to abandonment of various tin mining projects without proper disposal of the huge generated wastes and mine ponds scattered all over the area. These wastes have been washed by rain water into the stream water supplies thereby causing radiological pollution. The open cast mining method was generally used in predominantly flat plains of the Plateau as tin and columbite were concentrated in old stream beds (alluvial) having been washed down from the younger granite out cropping units [5].

The communities within the study area use mine ponds scattered all over the area for fishing, irrigation, recreation and drinking. The flowing water in the streams is used by the local miners to locally process the minerals and thereby depositing radioactive waste in the streams. They also use the same streams as source of drinking water and irrigation.

Geology of the Study Area

A major part of the Jos Plateau is underlain by non-orogenic granites of the Mesozioc Era [6] generally known as the younger granites. They form a distinct metallogenic province consisting essentially of biotite granite, riebeckitebiotite granite, hornblende fayalite granite, hornblende biotite granite, rhyolite, syentite, gabbro, dolerites and basalts with significant but varying amount of natural concentration of thorium, uranium and potassium which are radioactive.

Some of the rocks found here are also associated with alluvial deposits of cassiterite (tin oxide, $Sn0_2$) and columbite -oxide of tantalum – niobium, iron and manganese (Fe, Mn)(Ta, $Nb)_2O_6$), as well as radioactive mineral residues such as thorite ($ThSiO_4$) ziron ($ZiSiO_4$) and monazite (Ce, La, $Yt)PO_4$).

The rocks in this area therefore constitute a major source of radioactivity in surface water and a major radiation exposure to the inhabitants of the area through the water they consume. The objective of this study is to measure the level of natural radioactivity in surface water within the Naraguta sheet 168 (Fig 1) because of the implications of radiation on human health.

2. MATERIALS AND METHODS

The field data collection was carried out in the month of March, 2012. This period was chosen because it represents the peak of the dry season when water quantity determination into another and good accessibility is enhanced. Mine ponds and streams water samples were collected in 2 litres plastic and analysed with a proportional counter – MPC – 2000 – DP. The area of sample collection is bounded between longitude 8º31ˈE to 8º59ˈE and latitude 9º34ˈN to 9º55ˈN as shown in Fig. 1.

At every location, the surface radiation dose was measured at the surface and 1 meter above the surface using a Gamma Scout (W/alert version) radiation meter. The water quality parameters (conductivity, temperature, PH and Total Dissolved solids) were measured using DIST conductivity/TDS meters with automatic temperature compensation. An Etrex Garmin Global position system (GPS meter) was used to obtain coordinates and locations of the sampling points.

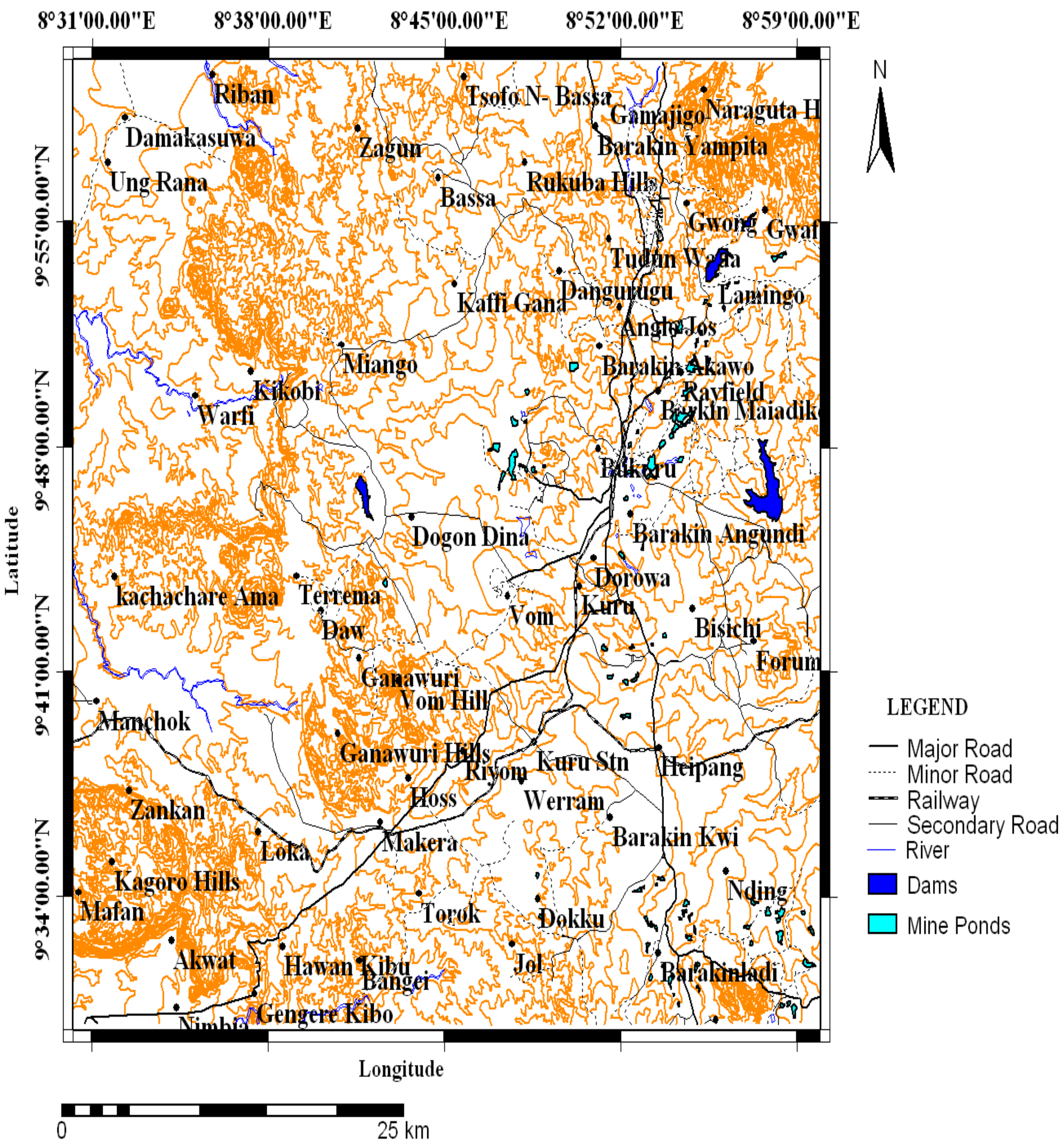

Fig. 1. Naraguta Topographical sheet 168 (9°30' N to 10°00' N and8°30' E to 9°00' E)

2.1 Sample Collection and Preparation

The procedure used for this work was stratified random and grid sampling of mine ponds water and streams water in the study area. Forty-eight (48) water samples consisting of twenty-five (25) mine ponds samples and twenty – three (23) streams water samples were collected from the mining areas covered by the Naraguta Topographical sheet 168. From each sampling point two litres of the water samples were drawn from each mine pond and stream source in a two litre plastic container. The amount of water collected was such that an air space of about 1% of the container capacity was left for thermal expansion. Samples were immediately acidified with nitric acid solution to reduce the pH, minimize precipitation and prevent the growth of micro-organisms. Immediately before sample collection, plastic bottles were rinsed again several times with water to be sampled. The samples were air tight and taken to the laboratory and held for atleast 24 hours before analysis.

Evaporation of samples was done using hot plates without stirring and at moderate heat in an open 600ml beaker. In the process of evaporation, when the level of the sample in the beaker was about 50ml, it was then transferred into a petri-dish and placed under infra-red light to completely dry the residue. The weight of the residue was obtained by subtracting the weight of the petri-dish from the weight of the petri-dish plus sample residue. An empty planchet was weighted after which about 0.077g of the residue was transferred to the planchet (ISO STANDARD). The Planchet plus residue was then weighted. A few drops of vinyl acetate were added on the samples to make then stick to the plancet to prevent scattering of the residue during counting.

2.2 Counting and Analyzes

The counting equipment is automated. The protocol involves entering present time, counting voltage and number of counting per cycles. Also to be entered are the counter characteristics (efficiency and background) volume of sample used and sample prepared efficiency. Results are displayed as raw count (count per minute), count rate activity and standard deviation. Acquisition was made in α – only mode and β-only mode.

2.2.1 Calibration of counting equipment

The calibration of the MPC 2000-DP consisted of setting the detector operating voltage and determining efficiency and background values for the count routine. Control charts were used to maintain instrument stability (MPC 2KV24 instruction manual). The calibration involved counting standards with known level of activity and background determination by counting blank samples.

2.2.2 Calibration results

Alpha and Beta Voltage= 1290V
Alpha only voltage = 750v
Beta efficiency using Sr-90 with reference number 14539 = 44%$\pm$0.61%
Alpha efficiency using Polonium-239 = 59.12% $\pm$0.68%
Count time (min) = 60
The background count for alpha and beta were measured to be :
Alpha background = 102.50cpm
Beta background = 102.60cpm

The net number of counts was obtained by subtracting the background from the actual number of counts produced by the source

The calculation formula for counter rate activity and parameters for a given sample given as [8].

Counter Rate (α, β) = Raw (α, β) count/count time in all modes (1)

$$\text{Activity }(\alpha,\beta) = \frac{rate(\alpha,\beta) - Bqd(\alpha,B)}{sampleefficency \times channelefficency} \quad (2)$$

2.3 Estimation of Annual Committed Effective Dose

The annual committed effective dose to an individual due to ingestion of natural radioactive material from all the water samples is estimated using the following equation [9].

$$\text{CED} = \text{A x IW x DCF} \quad (3)$$

Where

A = Sample activity concentration (Bq/l)
IW = Water intake. The quantity of water taken by each age group in a year are [3].

IW for teenage/adults (>12,yrs) is 730litres per year

IW for children (1 – 12yrs) is 365 per year
IW for infants ($\leq 1\ yr$) is 182.5 litres per year
DCF = Dose conversion factor (mSv/Bq)

Dose conversion factor used to calculate the internal radiation exposure by ingestion of radionulcides of radiological significance in drinking water for members of the public is 2.2 x 10^{-3} mSv/Bq [2].

3. RESULTS AND DISCUSSION

Table 1 shows the summary of the physical parameters of the water samples compared with the recommended and maximum permissible levels. It also shows that the geometric mean of the pH values, conductivity, total dissolved solids, temperature and the environmental gamma radiation dose level for mine ponds and stream water samples are 6.43 pH, 220.95μS/cm, 148.02 ppm, 25.51ºC and 0.29μSv/hr respectively for mine pond samples and 6.24pH, 356.65μS/cm, 268.87ppm, 25.67ºC and 0.24μSv/hr for stream sources. It reveals that the geometric means are within thew maximum permissible levels. Tables 2 and 3 present the gross alpha and gross beta activities in mine ponds and streams water samples in the mining areas of Plateau State and Tables 4 and 5 show the estimated Annual Committed Effective Dose. The alpha activities ranged from (0.047±0.010-6.640±0.032)Bq/l with a geometric mean of 0.410 ± 0.016 Bq/l and beta activities ranged from (0.001±0.009-6.680±0.039)Bq/l with a geometric mean of 0.125 ± 0.010Bq/l for mine ponds .For stream water samples,the gross alpha activities ranged from (0.140±0.011-4.310±0.013)Bq/l with a geometric mean of 0.642 ± 0.015 Bq/l and the gross beta activities ranged from (0.040±0.001-1.170±0.018)Bq/l with a geometric mean of 0.250 ± 0.008Bq/l. The high geometric means observed in stream water samples could be as a result of processed radioactive mineral dumped into the streams by the local miners.

From Table 4, the mean values of the annual committed effective dose to the infants, children and adults for alpha activities are 0.300mSv/yr, 0.599mSv/yr and 1.197mSv/yr for mine pond water samples while the mean values for beta emitting radionuclides are 0.202mSv/yr, 0.404mSv/yr and 0.809mSv/yr for the same sources. For stream water samples,the mean values of the CED for alpha emitting radionuclides are 0.354mSv/yr ,0.707mSv/yr and 1.415mSv/yr and the mean values of the CED for beta emitting radionuclides are 0.161mSv/yr, 0.321mSv/yr and 0.573mSv/yr. It is observed that all the values are above the ICRP guideline value of 0.1mSv/yr [3,1]. Figs. 2,3,4 and 5 show the comparison of committed effective dose for the different age groups due to alpha and beta emitting radionuclides in mine ponds and streams water samples with the ICRP standard of 0.1mSv/yr. The figures clearly reveal that that all the CED values for the age groups are above the allowed dose contribution from water intake. Although the CED values for teenagers and adults are higher than for infants and children due to higher quantity of water intake, the infants and children are more susceptible to high radiation dose related diseases through water ingestion due to their growing body cells. [10].

Table 1. Summary of the measurement of physical parameters of water in the study area

	Mine pond water		Stream water		WHO Standard [4,11]	
Parameter	**Range**	**Geo mean**	**Range**	**Geo mean**	**Recommended level**	**Maximum permissible level**
Gamma Dose rate (µSv/hr)	0.12 – 4.90	0.46	0.12 – 0.33	0.24	0.1	0.27
pH	5.43 -7.08	6.43	5.24 – 9.31	6.24	6.5	9.5
Temperature (^{0}C)	24.00 -31.00	25.56	20.00 -29.00	25.67	Variable	Variable
Conductivity (µS/cm)	100.00 -400.00	220.95	30.00 -900.00	356.65	400	1480
Total Dissolved Solids (TDS) (ppm)	67.00 -281.00	148.02	67.00 – 603.00	268.87	500	1000

Table 2. 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"	0.490±0.013	0.090±0.002
PWO2	Kari	1302	N09º30'59.3" E008º59'57.8"	0.720±0.016	0.620±0.019
PW03	SabonLayi B/Ladi	1320	N09º31'46.0" E008º53'27.5"	0.140±0.011	0.020±0.009
PW04	Police Barrack B/Ladi	1319	N09º33'02.4" E008º53'41.8"	0.180±0.012	0.680±0.014
PW05	Workshop B/Ladi	1313	N09º32'48.2" E008º53'32.1"	0.047±0.010	0.097±0.012
PW06	Sho Road	1320	N09º32'28.0" E008º53'05.1"	0.560±0.013	0.010±0.003
PW07	Rim	1202	N09º34'22.8" E008º44'58.4"	0.360±0.016	0.140±0.014
PW08	RahwolGassa	1293	N09º34'26.2" E008º53'51.0"	0.210±0.012	0.070±0.012
PW09	Heipang	1269	N09º40'10.4" E008º53'17.1"	0.440±0.014	0.290±0.015
PW10	ForonZabot	1241	N09º41'09.8" E008º51'25.4"	0.200±0.012	0.001±0.009
PW11	JantarKuru	1290	N09º41'30.5" E008º51'25.4	0.420±0.017	0.240±0.017
PW12	Bisichi	1290	N09º42'43.1" E008º54'30.5"	6.640±0.032	6.680±0.039
PW13	Angul Dee	1275	N09º44'59.4" E008º51'26.7"	0.500±0.011	0.010±0.009
PW14	Zawan	1281	N09º46'18.9" E008º52'10.4"	0.150±0.011	0.070±0.001
PW15	Mai-idon-Taro	1186	N09º42'55.4" E008º58'52.5"	0.34±0.015	0.110±0.013
PW16	Mai-idon-Taro B.	1192	N09º44'57.3" E008º59'36.2"	1.230±0.019	1.130±0.022
PW17	Sot-Gyel	1242	N09º47'10.6" E008º50'16.6"	2.660±0.017	0.250±0.021
PW18	SabonGidanKanar	1202	N09º47'16.8" E008º48'57.9"	0.620±0.017	0.060±0.001
PW19	Vom	1320	N09º42'13.8" E008º46'08.6"	0.230±0.011	0.010±0.009
PW20	Kwan	1335	N09º50'28.6" E008º55'27.0"	0.240±0.012	0.380±0.040
PW21	Doi-Du I	1339	N09º49'44.9" E008º55'03.0"	0.612±0.034	0.412±0.014
PW22	Doi-Du II	1303	N09º48'42.0" E008º55'00.2"	0.530±0.015	0.340±0.011
PW23	Gura-Topp	1329	N09º49'06.9" E008º54'12.8"	0.480±0.013	0.290±0.010
PW24	TCNN	1316	N09º48'03.9" E008º53'29.2"	0.361±0.012	0.520±0.010
PW25	Rayfield Resort	1330	N09º50'47.9" E008º54'56.9"	0.291±0.009	0.070±0.010
Control	Daika	NA	NA	NA	NA

PW: Pond Water

Table 3. 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”	0.790±0.013	0.330±0.013
SW02	Nafan Dredge	1232	N09º34’46.2” E008º59’01.5”	1.540±0.013	1.170±0.018
SW03	Ropp	1302	N09º31’57.9” E008º57’08.2”	1.040±0.014	0.600±0.018
SW04	BarakinLadi	1315	N09º32.05’5” E008º55’08.3”	0.430±0.013	0.250±0.013
SW05	Sho	1296	N09º32’11.3” E008º51’02.1”	0.550±0.014	0.100±0.011
SW06	RahwolGassa	1280	N09º34’55.2” E008º54’10.2”	1.260±0.015	0.830±0.016
SW07	Heipang	1264	N09º39’19.7” E008º53’21.9”	0.180±0.012	0.040±0.001
SW08	ForonZabot	1236	N09º41’09.7” E008º57’07.2”	0.62±0.016	1.170±0.018
SW09	Bisichi	1247	N09º42’29.2” E008º54’51.7”	4.310±0.013	0.500±0.010
SW10	JantarKuru	1258	N09º41.43.1” E008º53’09.3”	0.620±0.015	0.230±0.013
SW11	MarabaJama’a	1279	N09º43.22.5” E008º51’53.6”	1.130±0.010	0.390±0.050
SW12	Rim	1196	N09º35’24.9” E008º45’24.2”	0.490±0.013	0.090±0.003
SW13	Hoss	1220	N09º37’09.8” E008º43’33.6”	0.270±0.011	0.040±0.001
SW14	River Kaduna	936	N09º40’01.8” E008º37’48.8”	1.020±0.014	0.560±0.014
SW15	Vom	1333	N09º41’56.4” E008º42’33.1”	0.140±0.011	0.040±0.001
SW16	Angul Dee	1242	N09º47’01.5” E008º51’26.1”	0.580±0.010	0.180±0.011
SW17	DU	1299	N09º46’52.9” E008º53’01.4”	0.370±0.016	0.270±0.017
SW18	Gyel	1242	N09º47’12.5” E008º50’24.8”	0.660±.0.15	0.400±0.015
SW19	Sot-Gyel	1242	N09º47’12.5” E008º50’24.8”	0.870±0.014	0.380±0.013
SW20	Rayfield	1304	N09º49’50.2” E008º54’10.9”	0.330±0.012	0.220±0.003
SW21	Gura-Zot	1306	N09º51’48.0” E008º55’43.2”	0.270±0.011	0.041±0.010
SW22	British American Junction	1241	N09º53’56.0” E008º53’36.9”	2.130±0.050	1.120±0.022
SW23	Tina Junction	1235	N09º54’42.2” E008º54’44.6”	0.660±0.016	0.250±0.021
Control	Daika	1113	N09º28’01.1” E009º10’29.3”	0.003±0.001	0.011±0.002

Table 4. Committed effective dose (mSv/yr) for α – and β – activity due to intake of mine pond water for various age groups

		α - annual committed equivalent dose (mSv yr^{-1})			β - annual committed equivalent dose (mSvyr^{-1})		
Sample ID	**Location**	**infant ≤ 1yr**	**Children 1-12yrs**	**Teenager/Adult ≥12**	**infant ≤ 1yr**	**Children 1-12yrs**	**Teenager/Adult ≥12**
pw1	Ratatis(Dorowa)	0.197	0.393	0.787	0.036	0.072	0.145
pw2	Kari	0.289	0.578	1.156	0.249	0.498	0.996
pw3	Sabon Layi (B/Ladi)	0.056	0.112	0.225	0.008	0.016	0.032
pw4	Police Barrack (B/Ladi)	0.072	0.145	0.289	0.273	0.546	1.092
pw5	Workshop (B/Ladi)	0.019	0.038	0.076	0.039	0.078	0.156
pw6	Sho Road	0.225	0.450	0.899	0.004	0.008	0.016
pw7	Rim	0.145	0.289	0.578	0.056	0.112	0.225
pw8	Rahwol Gassa	0.084	0.169	0.337	0.028	0.056	0.112
pw9	Heipang	0.177	0.353	0.707	0.116	0.233	0.466
1pw0	Foron Zabot	0.080	0.161	0.321	0.001	0.001	0.002
pw11	Jantar Kuru	0.169	0.337	0.675	0.096	0.193	0.385
pw12	Bisichi	2.666	5.332	10.664	2.682	5.364	10.728
pw13	Angul Dee	0.201	0.402	0.803	0.004	0.008	0.016
pw14	Zawan	0.060	0.120	0.241	0.028	0.056	0.112
pw15	Mai Idon Taro	0.137	0.273	0.546	0.044	0.088	0.177
pw16	Mai Idon Taro B	0.494	0.988	1.975	0.454	0.907	1.815
pw17	Sot-Gyel	1.068	2.136	4.272	0.100	0.201	0.402
pw18	Sabon Gidan Kanar	0.249	0.498	0.996	0.024	0.048	0.096
pw19	Vom	0.092	0.185	0.369	0.004	0.008	0.016
pw20	Kwan	0.096	0.193	0.385	0.153	0.305	0.610
pw21	Doi-Du I	0.246	0.491	0.983	0.165	0.331	0.662
pw22	Doi-Du II	0.213	0.426	0.851	0.137	0.273	0.546
pw23	Gura-Topp	0.193	0.385	0.771	0.116	0.233	0.466
pw24	TCNN	0.145	0.290	0.560	0.209	0.418	0.835
pw25	Rayfield Resort	0.117	0.234	0.467	0.028	0.056	0.112
	Standard ICRP 1997	0.100	0.100	0.100	0.100	0.100	0.100

Table 5. Committed effective dose (mSv/yr) for α – and β – activity due to intake of stream water for various age groups

		α - annual committed equivalent dose (mSv yr^{-1})			β - annual committed equivalent dose (mSvyr^{-1})		
Sample ID	**Location**	**infant ≤ 1yr**	**Children 1-12yrs**	**Teenager/Adult ≥12**	**infant ≤ 1yr**	**Children 1-12yrs**	**Teenager/Adult ≥12**
sw1	Ratatis(Dorowa)	0.317	0.634	1.269	0.132	0.265	0.530
sw2	Nafan Dredge	0.618	1.237	2.473	0.470	0.940	0.272
sw3	Ropp	0.418	0.835	1.670	0.241	0.482	0.964
sw4	Barkinladi	0.173	0.345	0.691	0.100	0.201	0.402
sw5	Sho	0.221	0.442	0.883	0.040	0.080	0.161
sw6	Rahwol Gassa	0.506	1.012	2.024	0.333	0.667	1.333
sw7	Heipang	0.072	0.145	0.289	0.016	0.032	0.064
sw8	Foron Zabot	0.249	0.498	0.996	0.470	0.940	1.879
sw9	Bisichi	1.730	3.461	6.922	0.201	0.402	0.803
sw10	Jantar Kuru	0.249	0.498	0.996	0.092	0.185	0.369
sw11	Maraba Jama'a	0.454	0.907	1.815	0.157	0.313	0.626
sw12	Rim	0.197	0.393	0.787	0.036	0.072	0.145
sw13	Hoss	0.108	0.217	0.434	0.016	0.032	0.064
sw14	River Kaduna	0.410	0.819	1.638	0.225	0.450	0.899
sw15	Vom	0.056	0.112	0.225	0.016	0.032	0.064
sw16	Angul Dee	0.233	0.466	0.932	0.072	0.145	0.289
sw17	Du	0.149	0.297	0.594	0.108	0.217	0.434
sw18	Gyel	0.265	0.530	1.060	0.161	0.321	0.642
sw19	Sot-Gyel	0.349	0.699	1.397	0.153	0.305	0.610
sw20	Rayfield	0.132	0.265	0.530	0.088	0.177	0.353
sw21	Gura-Zot	0.108	0.217	0.434	0.017	0.033	0.066
sw22	British American Junction	0.855	1.710	3.421	0.450	0.899	1.799
sw23	Tina Junction	0.265	0.530	1.060	0.100	0.201	0.402
	Standard ICRP 1997	0.100	0.100	0.100	0.100	0.100	0.100

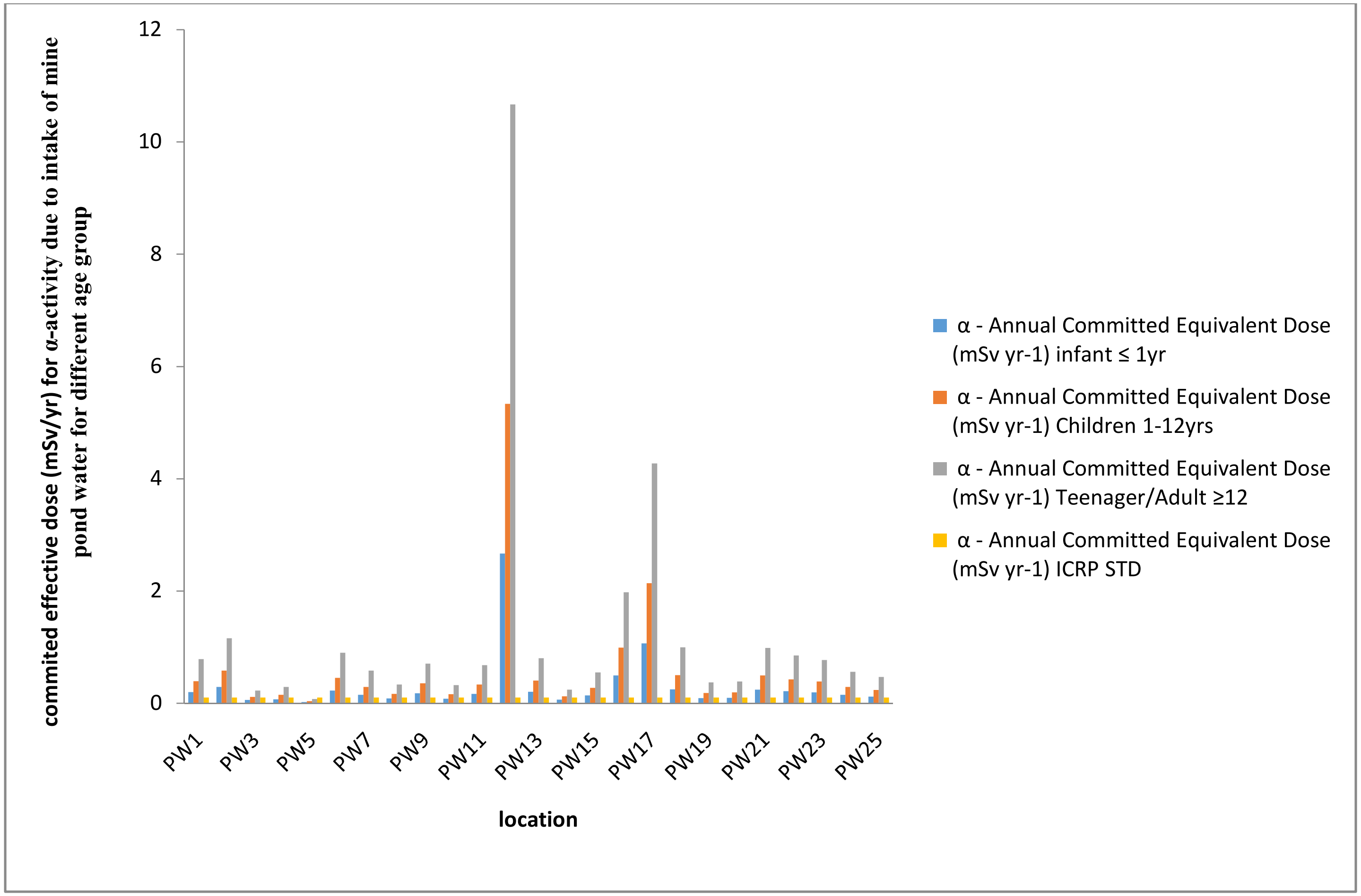

Fig. 2. Comparison of committed effective dose for different age group due to alpha activity in mine ponds

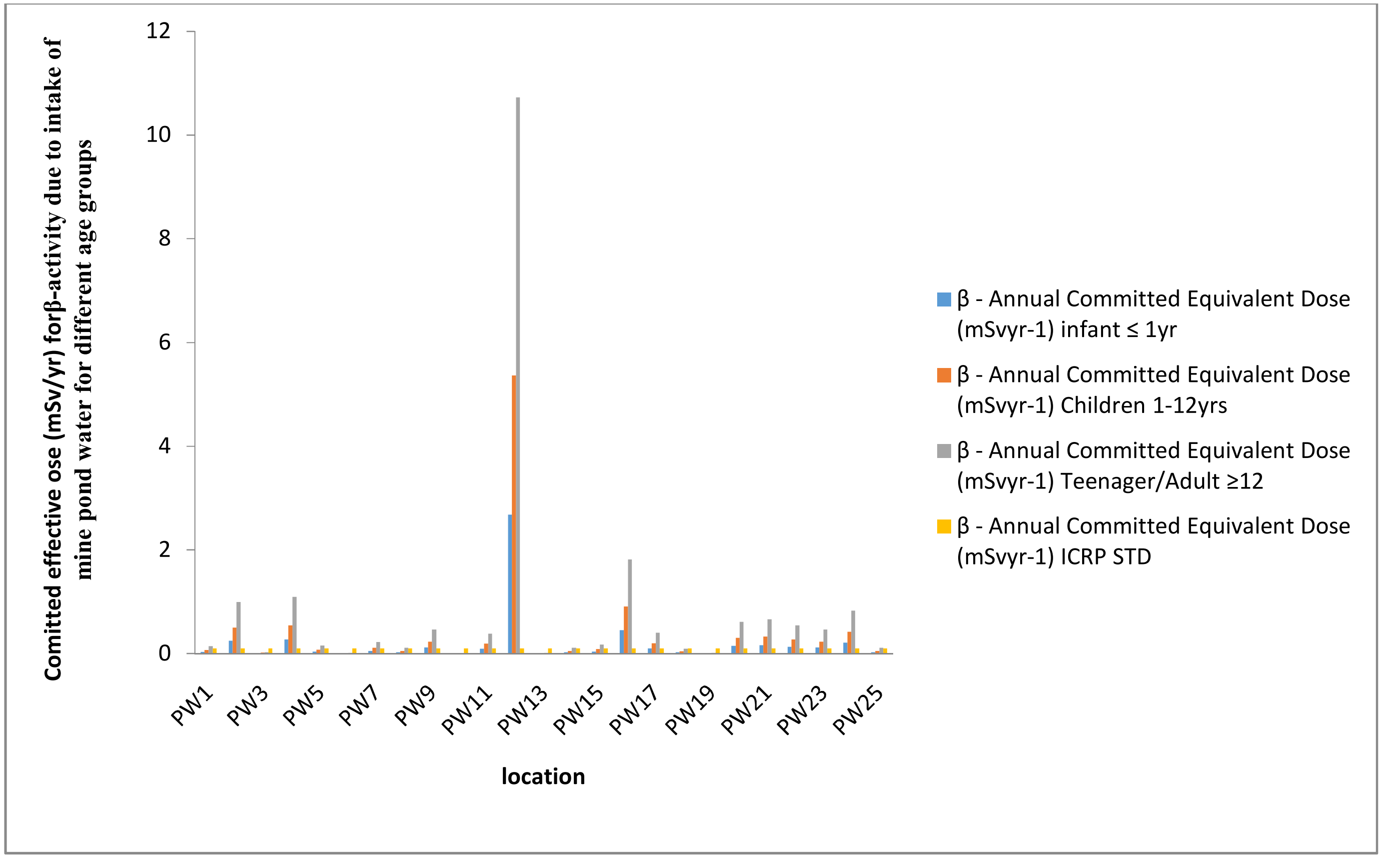

Fig. 3. Comparison of committed effective dose for different age group due to beta activity in mine ponds

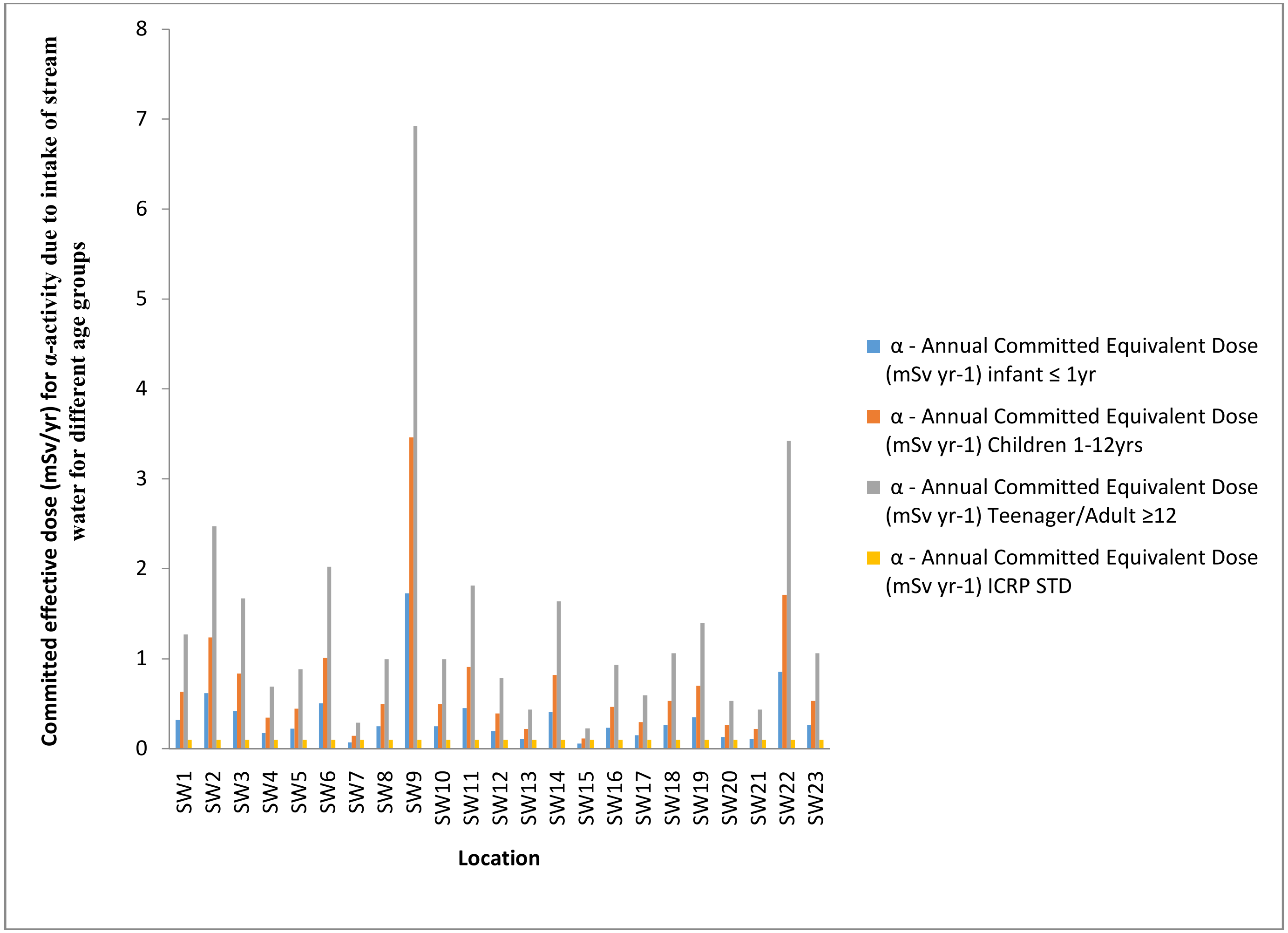

Fig. 4. Comparison of committed effective dose for different age group due to alpha activity in streams

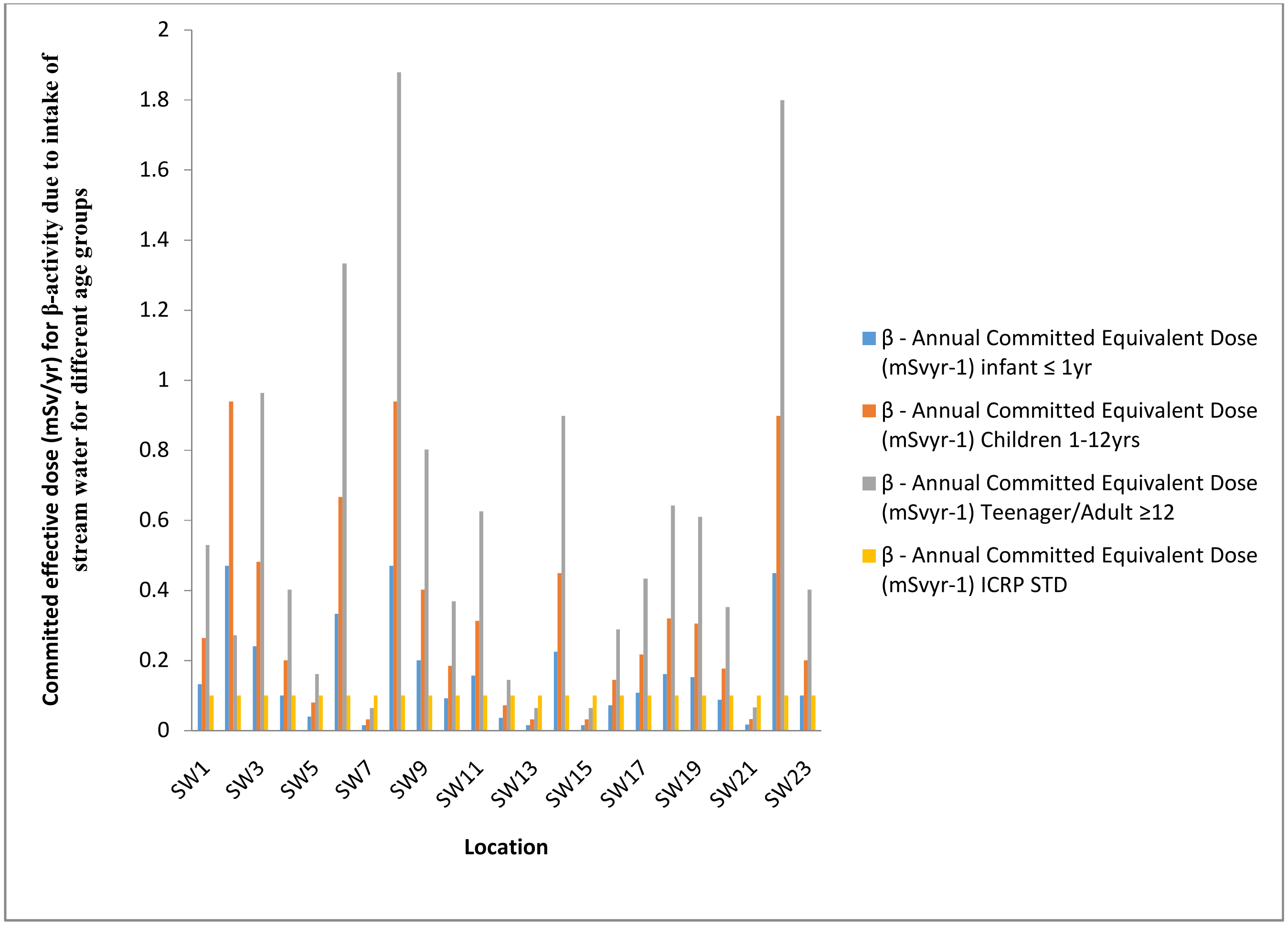

Fig. 5. Comparison of committed effective dose for different age group due to beta activity in streams

4. CONCLUSION

This study measured the gross alpha and gross beta radionuclides activities and also estimated the annual committed radiation dose in surface water in Tin mining environment of Plateau State. The gross alpha and beta activity concentrations in mine ponds and streams vary in quantity from one location to the other. The estimated dose intake for infants, children and teenagers/ Adults also showed variation between the sources. The enhanced radionuclides concentration levels observed in some mine ponds locations and streams can be attributed to the radionuclides exposed during mining and the radioactive tailings that are washed into same streams. We conclude that the generally high radioactivity levels observed in the study area have been influenced by mining activities and the indiscriminate disposal of mine tailings without following laid down regulations for this purpose.

We therefore recommend that areas with very high activity concentrations should not beused for drinking, agricultural and recreational activities by the host communities.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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