CONCENTRATIONS OF RADIONUCLIDES, MAJOR, TRACE AND RARE EARTH ELEMENTS OF SURFACE WATER SAMPLES IN OKHUOKHUO AREA, SOUTHERN NIGERIA

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Abstract: Nine surface water samples collected from springs and streams in Okhuokhuo area, southern Nigeria, were analyzed by gamma spectroscopy for natural (^{238}U, ^{232}Th and ^{40}K) and man-made ^{137}Cs radionuclides while the concentrations of 59 major, trace and rare earth elements were determined by inductively coupled plasma-mass spectrometry (ICP-MS). The results indicate that the activity concentrations of ^{238}U and ^{232}Th ranged from 0.64 to 0.80 Bq/L (averaging 0.71 Bq/L) and 0.91 to 1.45 Bq/L (averaging 1.17 Bq/L), respectively while ^{40}K and ^{137}Cs had activity concentration values below detection limit. The chemical compositions (Na, Mg, Ca, Mn, Fe, Ni, Cu, Zn, As, Se, Cd, Sb, Ba, Pb and U) and activity concentration values of ^{232}Th, ^{40}K and ^{137}Cs are below the World Health Organization (WHO) permissible limit whereas that of ^{238}U is slightly above the recommended limit. Varimax rotated Principal Component Analysis (PCA) revealed three hydrogeochemical processes operative in the surface water system. Factors 1 and 2 are related to the interactions of groundwater with the associated geological matrix while Factor 3 indicates anthropogenic processes within the study area.

Keywords: Anthropogenic processes, radionuclides, surface water, trace elements, Okhuokhuo

Introduction

The lignite-bearing Ogwashi-Asaba Formation is an important stratigraphic unit of the Niger Delta Basin with a maximum thickness of about 500 m (Reyment, 1965; Ezeigbo, 1989). It extends from Umuahia through Nnewi, Onitsha, Asaba to Benin City (Fig. 1). The formation consists of claystones, pebbly sandstone units, carbonaceous shale and lignite seams. Surface water (springs and streams) in Okhuokhuo area, Edo State, southern Nigeria, emanates from the aquiferous units of the carbonaceous Ogwashi-Asaba Formation (Fig. 1 and Table 1). In different parts of the world, coal act as aquifers and are exposed to trace elements in groundwater throughout their history. Finkelman (1981) observed that practically all the chemical elements in the periodic table have been found in coal. According to Ezeigbo (1989), the slightly acidic status of surface water in the Ogwashi-Asaba Formation is probably due to the leaching of organic acids from decaying vegetation, soils and lignite seams. Avwiri *et al*. (2007) investigated the natural radionuclides in water samples from boreholes collected in 29 locations in Port Harcourt, Nigeria. Ogala (2012) investigated the major and trace element compositions of lignite from the Neogene Ogwashi-Asaba Formation and noted that the concentrations of the trace elements in the lignite samples are relatively low in comparison with the world average values. Omo-Irabor and Ogala (2014) used statistical techniques to evaluate the concentration of thirty (30) hydrogeochemical and bacteriological characteristics of surface and groundwater in parts of Ogwashi-Asaba Formation, southern Nigeria. Ogala *et al*. (2019) reported extremely high ^{137}Cs activity concentration value of 618 Bq/kg in a lignite sample from Okhuokhuo.

This study focuses on investigating the chemical compositions (major, trace and rare earth elements) and radiological (^{232}Th, ^{238}U, ^{40}K and ^{137}Cs) constituents of surface water emanating from carbonaceous shale and lignite bed rocks in Okhuokhuo area, southern Nigeria.

Materials and Methods

Location and geology of the study area

Okhuokhuo lies between latitudes $6^{0}25^{/}$ - $6^{0}26^{/}$N and longitudes $6^{0}04^{/}$ - $6^{0}06^{/}$E, and covers an area of about 74 km^2 (Figs. 1 and 2). The study area is located within the Niger Delta sedimentary basin and is underlain by the Oligocene-Miocene Ogwashi-Asaba Formation (Reyment, 1965). The formation comprises of carbonaceous shale, lignite, claystones and pebbly sandstone units. The Ogwashi-Asaba Formation is underlain by the Eocene Ameki Formation and overlain by the Miocene-Recent Benin Formation (Table 1). The stratigraphic successions in the outcropping and subsurface units of the Cenozoic Niger Delta Basin is presented in Table 1.

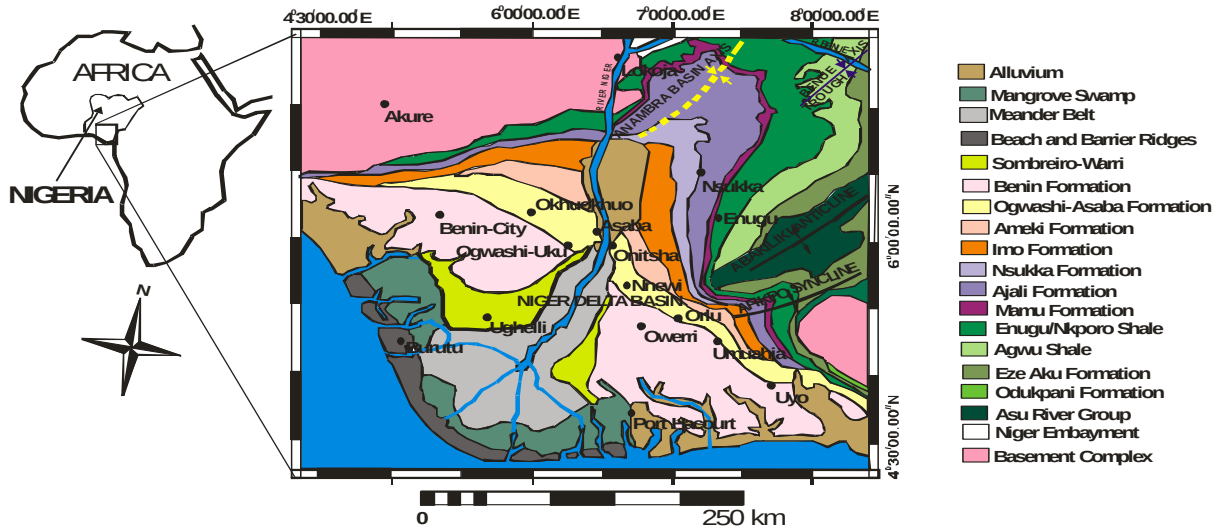

Fig. 1: Geological map of Nigeria showing Niger Delta Basin and adjacent units (Adapted from the 1984 edition of the GSN Geological map of Nigeria)

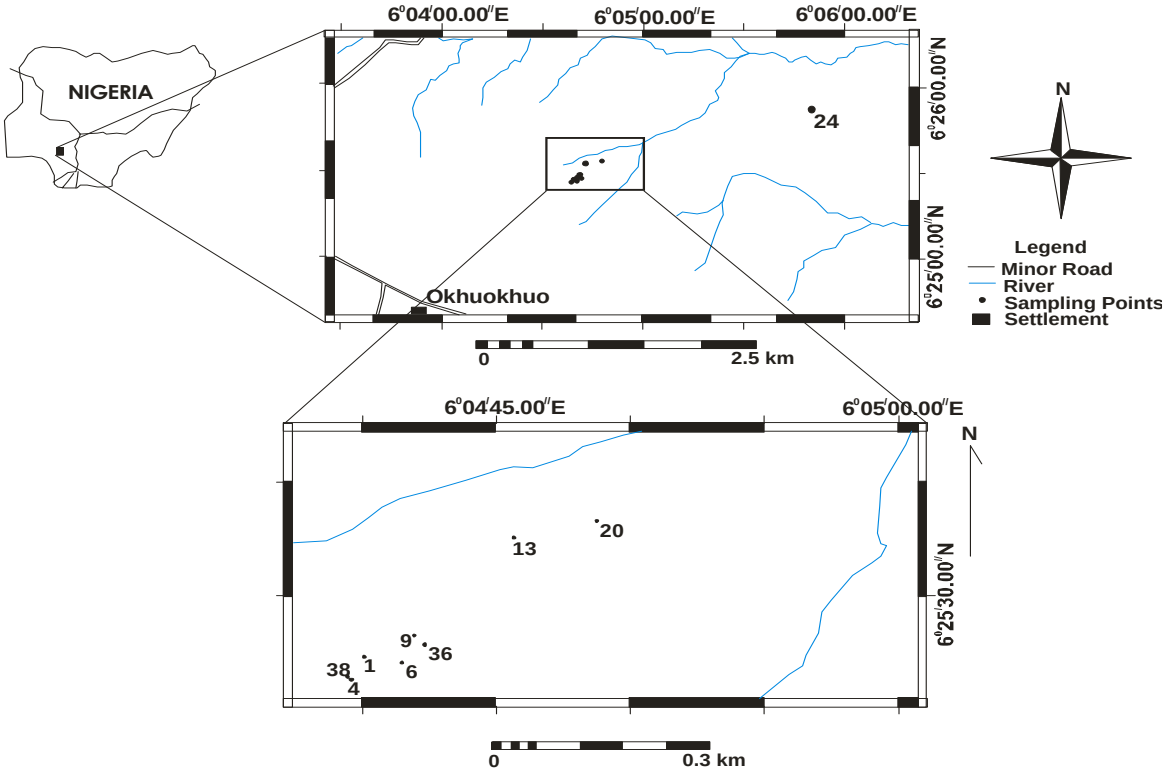

Fig. 2: Map of study area showing sampling points

Table 1: Stratigraphic successions in the Niger Delta Basin

ERA	PERIOD/AGE		Reyment (1965) OUTCROPPING UNITS	Short and Stauble (1967) SUBSURFACE UNITS	BASIN
Cenozoic	Quaternary		Benin Formation	Benin Formation / Agbada Formation / Akata Formation	CENOZOIC NIGER DELTA
	Neogene	Pliocene			
		Miocene	Ogwashi-Asaba Formation		
	Paleogene	Oligocene			
		Eocene	Ameki Formation/Nanka Sand		
		Paleocene	Imo Formation		

Sampling and methods

Nine samples of water were collected from springs (samples #1, 20 and 24) and streams (samples #4, 6, 13, 19, 36 and 38) within Okhuokhuo area, southern Nigeria (Fig. 2). Physical parameters such as temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) of the water samples were measured *in-situ* using a four-in-one waterproof Temperature/pH/EC/TDS meter (Model HANNA HI 991310) while turbidity was determined using a Micro TPI Turbidimeter.

For chemical analysis and determination of the radionuclides, duplicate water samples were collected into clean 1 litre plastic containers and preserved with nitric acid (pH<2) after collection to avoid the loss of analytes by absorption/adsorption. Nine water samples (#1, 4, 6, 13, 19, 20, 24, 36 and 38) were chemically analyzed for their major, trace and rare earth elements using Perkin Elmer Sciex ELAN 9000 ICP-MS while specific activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in four water samples (#1, 9, 20 and 38) were determined using gamma spectrometry at the Activation Laboratories, Ancaster, Canada. The gamma spectroscopy method assumes that the decay series are in radioactive equilibrium. The samples are sealed in a Marinelli beaker and stored for at least 28 days before analysis of ^{238}U, ^{232}Th and ^{40}K are determined by gamma spectrometry from daughter products of uranium and thorium series. The Gamma Spectroscopy system is a combination of a High Resolution Germanium Detector, a 32K Canberra Lynx Multi Channel Analyzer and a 4 inch lead shielding with copper/tin liner, to prevent high background counts. The multi-channel analyzer performs a Pulse Height Analysis (PHA) of the acquired spectrum of the samples. The Genie-2000 V3.2 software

locates and analyzes the peaks, subtracts background, identifies the nuclides, and corrects for parent/daughter interferences. A report is generated and activity is calculated in Bq/L. Certified Reference Materials of the International Atomic Energy Agency (IAEA-447 and IAEA-2012) were used to calibrate the Gamma Spectroscopy counting system.
The IBM® SPSS® Statistics version 20 was employed in performing the statistical analyses (Davis, 1986). Calcium, chromium, hafnium, scandium, niobium, molybdenum, silver, indium, tin, tellurium, tantalum, mercury, bismuth, potassium-40 and cesium-137 were excluded from further statistical analyses because they all had minimum values below detection limit.

Results and Discussion
The results of physicochemical parameters and specific activity concentrations of the natural and man-made radionuclides in the nine surface water samples analyzed are presented in Tables 2, 3, 4, 5 and 6. The descriptive statistics of these parameters are listed in Table 7.

Physical parameters
The pH values of the water samples range from 5.38 to 6.34, indicating a slightly acidic status for the surface water samples within Okhuokhuo area. The low pH values recorded in the water samples is probably due to the dissolution in groundwater of organic acids in the soil derived from the microbial degradation of decaying plants in the rainforest vegetation of the area (Ezeigbo, 1989; Olobaniyi et al., 2007). The nine water samples analyzed in this study display pH values within the recommended limits stipulated by both the EPA (2001) and WHO (2011). The total dissolved solids (TDS) ranges from 5.8 to 18.21 mg/l with an TDS value of 10.11 mg/l (Tables 2 and 7). The low TDS values (< 20 mg/l) permits the classification of the surface water in the study area as freshwater. Also the TDS value of 10.11 mg/l falls below the Environmental Protection Agency (EPA, 2001) and World Health Organization (WHO, 2011) permissible limits of 500 mg/l and < 1000 mg/l respectively (Table 7) The electrical conductivity (EC) values ranged from 8.9 to 32.11 µS/cm with an average of 16.7 µS/cm (Tables 2 and 7). The average EC value (16.7 µS/cm) of the water sample falls below the Environmental Protection Agency (EPA, 2001) permissible limits of 1000 mg/l (Table 7). The turbidity ranged from 0.1 to 3.21 nephelometric turbidity units (NTU) with an average of 1.37 NTU (Tables 2 and 7). These values falls below the WHO (2011) recommended limits of < 5 NTU (Table 7). The low values of pH (mean~5.63), TDS (mean~10.11 mg/l), EC (mean~16.70 µS/cm) and turbidity (mean~1.37 NTU) indicate that the surface water in the study area would be suitable for use in domestic and farm irrigation purposes. Furthermore, the results obtained in this study is similar and also in agreement with those of Olobaniyi et al. (2007) and Omo-Irabor and Ogala (2014).

Table 2: Physical parameters of surface water samples from Okhuokhuo

Parameters	L1	L4	L6	L9	L13	L20	L24	L36	L38
PH	5.46	5.38	5.64	5.39	5.6	5.57	5.58	6.34	5.72
Total dissolved solids (mg/l)	10	9.1	6.7	6.9	7.4	5.8	11.39	18.21	15.52
Electrical conductivity (µS/cm)	15.5	13.7	10.1	10.9	11	8.9	19.17	32.11	28.9
Temperature (ºC)	31.3	31.2	30.8	31.2	31.3	31.3	31.3	32.6	31.5
Turbidity (NTU)	1.82	1.55	1.48	1.89	1.43	0.1	0.41	3.21	0.41

Table 3: Concentrations of major elements (µg/L) in surface water samples from Okhuokhuo

Elements	DL	L1	L4	L6	L9	L13	L20	L24	L36	L38
Na	**5**	951	1190	939	1140	1270	1140	888	1030	1170
Mg	**2**	190	248	196	247	282	200	225	262	243
Al	**2**	77	118	56	187	80	68	80	68	125
Si	**200**	5000	5100	5000	5100	5000	5400	6200	5400	5200
K	**30**	130	240	130	230	300	120	490	140	220
Ca	**700**	< 700	< 700	< 700	< 700	800	< 700	< 700	< 700	< 700
Ti	**0.1**	< 0.1	0.1	0.1	0.2	0.5	0.3	0.2	0.7	1.2
Mn	**0.1**	14	13.7	13.3	14.7	16.5	13.3	14.4	12.9	13.2
Fe	**10**	30	90	30	220	80	30	20	80	60

DL = Detection limit

Major, trace and rare earth elements composition
The concentrations of major, trace and rare earth elements in the water samples are listed in Tables 3, 4 and 5. The concentrations of Si, Na, Mg, K, Al, Ca, Fe, Mn and Ti are in the ranges, 500 to 6200 µg/l, 888 to 1270 µg/l, 190 to 282 µg/l, 120 to 490 µg/l, 56 to 187 µg/l, <700 to 800 µg/l, 20 to 220 µg/l, 12.9 to 16.5 µg/l and <0.1 to 1.2 µg/l respectively (Table 3). Lithium, Be, V, Co, Ni, Cu, Zn, Ga, Ge, As, Se, Rb, Sr, Y, Zr, Nb, Cd, Sb, Cs, Ba, Hf, Tl, Pb, Th and U have concentration values ranging from 1-3 µg/l, <0.1 to 2 µg/l, <0.1 to 0.7 µg/l, 0.47 to 1.75 µg/l, 0.5 to 2.3 µg/l, 0.3 to 2.1 µg/l, 1.6 to 15.5 µg/l, 0.1 to 0.55 µg/l, 0.04 to 0.12 µg/l, 0.05 to 0.29 µg/l, <0.2 to 0.4 µg/l, 0.61 to 2.33 µg/l, 4.4 to 6.57 µg/l, 0.35 to 1.38 µg/l, <0.01 to 0.06 µg/l, <0.005 to 0.007 µg/l, <0.01 to 0.02 µg/l, <0.01 to 0.12 µg/l, 0.06 to 0.13 µg/l, 11 to 41.8 µg/l, <0.001 to 0.002 µg/l, 0.01 to 0.05 µg/l, 0.05 to 2.86 µg/l, <0.001 to 0.02 µg/l and 0.06 to 0.37 µg/l respectively while Cr, Sc, Mo, Ag, In, Sn, Te, Ta, W, Hg and Bi all had concentration values below detection limits (Table 4). The concentrations of rare earth elements: La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu ranged from 0.19 to 0.86 µg/l, 0.35 to 2.14 µg/l, 0.07 to 0.4 µg/l, 0.3 to 1.76 µg/l, 0.07 to 0.44 µg/l, 0.01 to 0.1 µg/l, 0.07 to 0.44 µg/l, 0.01 to 0.08 µg/l, 0.06 to 0.38 µg/l, 0.01 to 0.07 µg/l, 0.03 to 0.19 µg/l, 0.004 to 0.02 µg/l, 0.02 to 0.14 µg/l and 0.004 to 0.02 respectively (Table 5). These concentration values falls below the EPA (2001) and WHO (2011) recommended limits (Table 7) for drinking water.

Table 4: Concentrations of trace elements (µg/L) in surface water samples from Okhuokhuo

Elements	DL	L1	L4	L6	L9	L13	L20	L24	L36	L38
Li	1	1	2	2	2	3	2	3	2	2
Be	0.1	< 0.1	0.1	< 0.1	0.2	0.2	0.1	0.2	0.1	0.1
Sc	1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
V	0.1	0.1	0.2	0.2	0.7	0.4	0.2	< 0.1	0.4	< 0.1
Cr	0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Co	0.005	0.806	1.26	0.702	1.16	1.75	0.473	0.768	0.729	1.25
Ni	0.3	1	1.6	0.7	1.5	2.3	0.5	0.9	0.8	1.6
Cu	0.2	1	0.9	0.7	1.4	2.1	0.3	1.5	0.7	0.8
Zn	0.5	2.2	5.8	1.6	4.7	15.5	2.1	3.4	2.4	4.7
Ga	0.01	0.39	0.29	0.1	0.55	0.18	0.18	0.28	0.12	0.27
Ge	0.01	0.09	0.07	0.04	0.12	0.05	0.05	0.08	0.04	0.07
As	0.03	0.16	0.14	0.05	0.29	0.1	0.08	0.13	0.07	0.14
Se	0.2	0.3	0.2	< 0.2	0.4	< 0.2	< 0.2	0.3	< 0.2	0.3
Rb	0.005	0.625	1.01	0.609	1.03	1.2	0.681	2.33	0.814	0.964
Sr	0.04	4.4	4.93	4.47	5.03	5.62	4.55	6.57	5.5	4.87
Y	0.003	0.924	1.03	0.375	1.68	0.655	0.605	1.02	0.35	0.994
Zr	0.01	< 0.01	0.03	0.01	0.04	0.06	0.02	< 0.01	0.05	0.05
Nb	0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	< 0.005	0.007
Mo	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ag	0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Cd	0.01	< 0.01	0.02	< 0.01	0.02	0.02	0.01	0.01	< 0.01	0.02
In	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Sn	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Sb	0.01	0.06	0.12	< 0.01	0.03	0.02	< 0.01	0.01	< 0.01	< 0.01
Te	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Cs	0.001	0.057	0.097	0.059	0.099	0.08	0.067	0.128	0.086	0.095
Ba	0.1	11.7	12.3	11	12.8	13.6	17	41.8	15.8	12
Hf	0.001	0.001	0.001	< 0.001	0.002	0.002	< 0.001	< 0.001	0.001	0.002
Ta	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
W	0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02	< 0.02
Hg	0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Tl	0.001	0.013	0.036	0.012	0.034	0.049	0.011	0.031	0.02	0.031
Pb	0.01	0.17	0.16	0.05	0.27	0.16	0.08	0.25	2.86	0.06
Bi	0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3	< 0.3
Th	0.001	< 0.001	0.006	0.001	0.007	0.017	0.006	0.002	0.009	0.007
U	0.001	0.348	0.174	0.101	0.372	0.098	0.061	0.19	0.073	0.122

DL = Detection limit

Table 5: Concentrations of rare earth elements (µg/L) in water samples from Okhuokhuo

Elements	DL	L1	L4	L6	L9	L13	L20	L24	L36	L38
La	0.001	0.572	0.483	0.187	0.856	0.339	0.499	0.38	0.212	0.4
Ce	0.001	1.36	1.17	0.35	2.14	0.79	0.767	1.04	0.422	0.908
Pr	0.001	0.3	0.214	0.069	0.395	0.137	0.145	0.178	0.072	0.165
Nd	0.001	1.36	0.954	0.298	1.76	0.596	0.567	0.762	0.296	0.724
Sm	0.001	0.364	0.23	0.075	0.44	0.143	0.119	0.188	0.067	0.172
Eu	0.001	0.078	0.051	0.016	0.096	0.032	0.026	0.048	0.014	0.039
Gd	0.001	0.318	0.247	0.076	0.436	0.144	0.127	0.195	0.068	0.19
Tb	0.001	0.055	0.043	0.013	0.076	0.025	0.021	0.034	0.012	0.032
Dy	0.001	0.272	0.215	0.072	0.382	0.134	0.109	0.178	0.06	0.17
Ho	0.001	0.05	0.041	0.013	0.071	0.026	0.021	0.034	0.012	0.032
Er	0.001	0.13	0.107	0.036	0.186	0.07	0.055	0.092	0.031	0.085
Tm	0.001	0.018	0.013	0.005	0.023	0.009	0.007	0.012	0.004	0.011
Yb	0.001	0.115	0.082	0.029	0.141	0.059	0.041	0.073	0.024	0.064
Lu	0.001	0.017	0.012	0.005	0.021	0.009	0.007	0.011	0.004	0.01

DL = Detection limit

Radionuclides

The ^{232}Th and ^{238}U activity concentrations of the surface water samples range from 0.91 to 1.45 Bq/L and 0.64 to 0.80 Bq/L, respectively (Table 6). The ^{40}K and ^{137}Cs activity concentrations are below detection limits in all the samples analyzed. Except for sample L20 having activity concentration value of 0.91 Bq/L, all the other samples (L1, L9 and L38) display slightly higher ^{232}Th activity concentrations of 1.19 Bq/L, 1.45 Bq/L and 1.11 Bq/L, respectively. The recommended guidance levels of ^{137}Cs, ^{232}Th, and ^{238}U radionuclides in drinking water are 10, 1 and 10 Bq/L, respectively WHO (2011) (Tables 6 and 7).

Table 6: Activity concentrations (Bq/L) of radionuclides in water sapmles from Okhuokhuo

Analyte/ Sample #	Detection limit	L1	L9	L20	L38	WHO (2011)
K-40	**0.05**	< 0.05	< 0.05	< 0.05	< 0.05	
Th-232	**0.1**	1.19	1.45	0.91	1.11	1
U-238	**0.1**	0.8	0.64	0.69	0.7	10
Cs-137	**0.02**	< 0.02	< 0.02	< 0.02	< 0.02	10

Table 7: Descriptive statistics of physiochemical parameters and activity concentrations of radionuclides in the surface water samples from Okhuokhuo

Parameters (N=9)	Minimum	Maximum	Mean	Standard deviation	EPA (2001)	WHO (2011)
pH	5.38	6.34	5.63	0.29	5.5-8.5	6.5-8.5
TDS (mg/l)	5.8	18.21	10.11	4.26	500	600-1000
EC(µS/cm)	8.9	32.11	16.7	8.47	1000	
Temperature (ºC)	30.8	32.6	31.39	0.49	25	
Turbidity (NTU)	0.1	3.21	1.37	0.96		<5
			(Bq/l)			
^{232}Th	0.91	1.45	1.17	0.22		1
^{238}U	0.64	0.8	0.71	0.07		10
			(µg/l)			
Na	888	1270	1079.78	132	200000	200000
Mg	190	282	232.56	31.88		50000
Al	56	187	95.44	41.3		
Si	5000	6200	5266.67	384.06		
K	120	490	222.22	118.51		
Ca	0	800	88.89	266.67		100000
Ti	0	1.2	0.37	0.38		
Mn	12.9	16.5	14	1.11		100
Fe	20	220	71.11	61.73	200	300
Li	1	3	2.11	0.6		
Be	0	0.2	0.11	0.08		
V	0	0.7	0.24	0.22		
Co	0.47	1.75	0.99	0.4		
Ni	0.5	2.3	1.21	0.58	20	70
Cu	0.3	2.1	1.04	0.54		2000
Zn	1.6	15.5	4.71	4.29	3000	100
Ga	0.1	0.55	0.26	0.14		
Ge	0.04	0.12	0.07	0.03		
As	0.05	0.29	0.13	0.07		10
Se	0	0.4	0.17	0.17		40
Rb	0.61	2.33	1.03	0.53		
Sr	4.4	6.57	5.1	0.7		
Y	0.35	1.68	0.85	0.41		
Zr	0	0.06	0.03	0.02		
Nb	0	0.01	0.0008	0.002		
Cd	0	0.02	0.011	0.009	5	3
Sb	0	0.12	0.03	0.04		20
Cs	0.06	0.13	0.09	0.02		
Ba	11	41.8	16.44	9.71		700
Tl	0.01	0.05	0.03	0.01		
Pb	0.05	2.86	0.45	0.91	50	10
Th	0	0.02	0.006	0.005		
U	0.06	0.37	0.17	0.12		30
La	0.19	0.86	0.44	0.2		
Ce	0.35	2.14	0.99	0.54		
Pr	0.07	0.4	0.19	0.1		
Nd	0.3	1.76	0.81	0.48		
Sm	0.07	0.44	0.2	0.13		
Eu	0.01	0.1	0.04	0.03		
Gd	0.07	0.44	0.2	0.12		
Tb	0.01	0.08	0.04	0.02		
Dy	0.06	0.38	0.18	0.1		
Ho	0.01	0.07	0.03	0.02		
Er	0.03	0.19	0.09	0.05		
Tm	0	0.02	0.01	0.006		
Yb	0.02	0.14	0.07	0.04		
Lu	0	0.02	0.01	0.006		

Statistical treatment

The results of varimax rotated Principal Component Analysis (PCA) revealed three factors explaining 100 % of the total variance (Table 8). Factor 1 which accounts for 55.9 % of the total variance display high positive loadings for turbidity, ^{232}Th, Al, V, Mn, Fe, Cu, Ga, Ge, As, Se, Y, Sb, Pb, U and REEs (rare earth elements). Factor 2 show high positive loadings for Na, Li, Be, Mg, Al, K, Zn, Rb, Sr, Zr, Cd, Cs, Tl and Th accounts 30.1 % of the total variance while Factor 3 accounting for 14 % of the total variance display high positive loadings for TDS, EC, water temperature, Ti, Co and Ni (Table 8). The loadings in Factors 1 and 2 relates to contribution from associated geological matrix and marine water while Factor 3 indicate anthropogenic processes.

Table 8: Varimax rotated component loadings of 52 physiochemical and radiological parameters on three significant components explaining 100% of the total variance

Parameters	Factor 1	Factor 2	Factor 3
pH	**-.825**	.196	.529
Total dissolved solids	-.207	.091	**.974**
Electrical conductivity	-.257	.185	**.949**
Temperature	-.635	.094	**.767**
Turbidity	**.976**	-.212	.047
^{232}Th	**.940**	.315	.129
^{238}U	-.023	**-.931**	.365
Na	-.394	**.914**	-.095
Li	-.352	**.907**	-.229
Be	.245	**.911**	-.331
Mg	.234	**.923**	.306
Al	**.629**	**.771**	.102
Si	**-.826**	.314	-.469
K	.379	**.823**	.422
Ti	-.528	.547	**.650**
V	**.684**	.481	-.548
Mn	**.962**	.098	-.256
Fe	**.715**	**.672**	-.192
Co	.430	.581	**.691**
Ni	.458	.568	**.684**
Cu	**.943**	.226	.243
Zn	.303	**.842**	.447
Ga	**.982**	.190	.018
Ge	**.976**	.209	.059
As	**.909**	.417	.008
Se	**.808**	.238	.540
Rb	.306	**.914**	.266
Sr	.300	**.945**	.130
Y	**.836**	.545	.058
Zr	-.105	**.947**	.304
Cd	-.012	**.990**	.140
Sb	**.761**	**-.645**	.077
Cs	.211	**.945**	.251
Ba	-.592	.068	**-.803**
La	**.858**	.257	-.446
Ce	**.956**	.256	-.144
Pr	**.992**	.053	-.111
Nd	**.998**	.033	-.057
Sm	**.999**	-.047	-.003
Eu	**1.000**	-.019	.009
Gd	**.993**	.115	-.006
Tb	**.994**	.113	-.009
Dy	**.989**	.148	.007
Ho	**.986**	.164	-.001
Er	**.984**	.177	.006
Tm	**.996**	.066	.054
Yb	**.999**	.003	.048
Lu	**.999**	.021	.028
Tl	.401	**.826**	.397
Pb	**.953**	.106	-.285
Th	-.265	**.955**	-.130
U	**.983**	-.175	.058
Eigen values	**29.080**	**15.636**	**7.284**
% of Variance	**55.923**	**30.070**	**14.008**
Cumulative %	**55.923**	**85.992**	**100.000**

Conclusion

The physical (water temperature, pH, electrical conductivity, total dissolved solids and turbidity), chemical (major, trace and rare earth elements) and radiological (^{232}Th, ^{238}U, ^{40}K and ^{137}Cs) constituents of surface water samples emanating from lignite and carbonaceous shale bed rocks in Okhuokhuo area, southern Nigeria, have been investigated. The water temperature, pH, EC, TDS and turbidity have values ranging from 30.80 to 32.60^{o}C, 5.38 to 6.34, 8.90 to 32.11 µS/cm, 5.80 to 18.21 mg/l and 0.10 to 3.21 NTU respectively. These results indicate a slightly acidic and low salinity status for the water samples. The generally low TDS values of the water samples in the study area permits their classification as freshwater. The concentrations of Na, Mg, Ca, Mn, Fe, Ni, Cu, Zn, As, Se, Cd, Sb, Ba, Pb, U and other physical parameters (pH, TDS and turbidity) fall below the World Health Organization recommended limit. The chemical compositions and activity concentrations of ^{232}Th, ^{238}U, ^{40}K and ^{137}Cs does not pose any risk to human health or environmental hazards.

Conflict of Interest

Author declares that there is no conflict of interest in the study

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