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Determination of Heavy Minerals and Natural Radionuclides in Beach Sediments from Badagry, Southwestern Nigeria

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Abstract

Beach sediments contain both heavy and light minerals that carry natural radionuclides in different quantities. Heavy minerals can pose threat to health if such sediments are used in building constructions. Much study has not been done on Badagry beach sediments to determine the heavy minerals and natural radionuclides. The highest mean activity concentrations of the natural radionuclides (^{40}K, ^{238}U and ^{323}Th) in the sediments were 7.98 ± 32.51 - 228.17 ± 36.92 for ^{40}K; 3.84 ± 17.80 - 194.50 ± 24.84 for ^{238}U and 0.09 ± 27.36 - 78.43 ± 15.39 for ^{232}Th . The radium equivalent varied between 19.82 and 318.67. The radium external index ranged from 0.01 to 0.86. The radium equivalent and external hazard index values were below the United Nations Scientific Committee on the effects of atomic radiation recommended international limits of 370BqKg^{-1} and 1.0 respectively. The ZTR index obtained show immature to mature sediments.

Keywords: Beach sediment. Heavy minerals. Natural Radionuclides, Radium equivalent, ZTR Index

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1 Introduction

The earth crust and mantle produce radioactive elements. These radioactive elements are of different quantities depending on the mineralogy and the available rocks of a particular region. The radioactive elements and their respective quantities of sand sediment depend on the host rocks. Potassium-40 (^{40}K), uranium-238 (^{238}U) and thorium-232 (^{232}Th) are the main natural primordial radionuclides. The provenance, grain seize and mineral type, determine the activity concentration of these naturally occurring radionuclides [1]. Radioactive method is one of the geophysical methods that have been used for geothermal exploration ([2],[3]).

Awareness of exposure to natural radioactivity in both the industrial and environmental domain is growing. Unfortunately common errors in associating ambient radioactivity with nuclear industry and indeed the assumption that radioactivity is in some way unnatural frequently arises. Application of radioactivity survey to environmental problems such as detection of radioactive pollution in soils, groundwater and air are of significant importance [4]. In their Gamma ray spectrometric analysis on bituminous sand collected from Okitipupa, a reverine area in Ondo State, Nigeria,[4] found low activity levels and hence concluded that the sand in the area does not constitute any health hazard. Joshua and [5] carried out analysis of Grain-size and heavy minerals of River Osun, Nigeria, sediments. They found the maximum ZTR index obtained shows that the sediments are mineralogically immature.

Beach sediments are mineral deposits formed through weathering and erosion of either igneous or metamorphic rocks. Thorium and uranium accessory minerals to some extend are present in these rocks. The weathering of these rocks allows these minerals to migrate and enrich in sediments. Natural radioactivity studies of beach sediments provide a better understanding for mineralogy, geochemical, economical implications and radiological significance.

Heavy minerals are known to harbor large concentrations of naturally occurring radionuclides of the uranium and thorium decay series in their crystalline structure. Meanwhile, light minerals such as feldspar and quartz have low concentrations of uranium and thorium, but may possess large concentrations of potassium, which has an isotope 40 (^{40}k) a natural emitter of gamma ray, feldspar in particular. Light and heavy minerals that are radioactive emit characteristic gamma ray [6].

The objectives of this research work are: to identify and determine percentage composition of heavy minerals; to determine the activity concentration of natural radionuclides in the beach sediments and to assess the radiological hazard index in the beach sediments.

2 Material and Method

2.1 Sample Collection and Preparation

Samples were collected in Badagry beach, located in Lagos, South-western Nigeria. The total study area spread over from Lat.:06^{o}23' 48.5"N; Long.:002^{o}50'7.5"E to Lat.:06^{o}23' 37.1"N; Long.:02^{o}48'17.28"E which covers an area of about 2 km.

Twenty six beach sediment samples were collected at thirteen different spots, which covered about 2 km.The exact position of each sampling spot was recorded using hand held GARMIN Global Positioning System (GPS). The samples were collected from 10-20 m away from the high tide.

The collected samples were dried in an oven at 100-110^{o}C until the constant dry weight was obtained. The samples were then sieved through 2-mm mesh sizes sieve to remove stone, pebbles and other macro-impurities. The homogenous samples were placed in 200g lots by weight airtight PVC container and closed tightly with outer cap. Each container was sealed hermitically and externally using cellophane tape and kept aside for about a month to ensure equilibrium between Radium and its daughter nuclei before being taken for gamma ray spectrometric analysis.

2.2 Heavy Mineral Separation

The heavy minerals in beach sediment are defined by a lower limit of specific gravity, 2.85, which corresponds to that of common separating fluid-bromoform. Thirteen (13) sandstone samples were analyzed for the purpose of having a uniform size range. The samples were separated by the specific gravity method, where 5g of each sample was poured into the bromoform in a separating funnel, stirred vigorously and allowed to settle gravitationally. The settled minerals were then flushed out through the separating funnel tap into another funnel lined with filter paper.

The resulting filtrates (heavy minerals) were then treated with dilute HCl and acetone (CH_3COOH) to remove carbonate clay or iron oxide coating and bromoform. After being over dried, the heavy minerals were mounted on micro-glass sides with Canada balsam. The slides were later examined under a petrographic microscope using transmitted light to observe the minerals. Each mineral type was identified based on such optical characteristics as colour, pleochroism, absorption, relief, extinction and birefringence, size, crystal form, elongation, inclusions, cleavage and twinning. The opaque were further examined under reflecting light [7]. This analysis was carried out in the geochemical laboratory for the Department of Geology, University of Ibadan.

The ZTR index which is a quantitative definition of mineral assemblage was calculated using the percentage of the combined, zircon, tourmaline and rutile grains for each sample.

$$\text{ZTR\% INDEX} = \frac{\text{Zircon} + \text{Tourmaline} + \text{Rutile}}{\sum \text{non} - \text{opaque}} \times 100 \quad (1)$$

The ZTR index expressed as a percentage was calculated for the samples to ascertain the mineralogical maturity index. The composition of the heavy minerals as giving by the analysis gives a preponderance of the meta-stables group over the ultra stable for the non-opaque minerals. The opaque minerals have ilmenite and ilmonite with formal predominating. The ultra-stable are the zircon, tourmaline and rutile (ZTR) group, while the meta-stables are garnet, epidote etc.

2.3 Description of Counting Assembly

The detector assembly consists of the NaI (TI) crystal detector of size 7.6cm × 7.6cm (model no.:80 series Canberra Inc.) coupled to a Canberra series 10 along a multichannel analyzer (MCA) (model no: 1104) through a pre-amplifier. Its lead castle acts as a shield to reduce the count due to external background radiation. The multichannel analyzer has an input high voltage power supply (HVPS) and rechargeable batteries (NiCd) for portability. Each of the plastic containers was placed on the detector inside the lead castle one after the other for counting. The time for counting each sample was set to 18000 (5 hour). The standard sources of natural uranium, natural thorium and potassium were obtained from radiation laboratory Department of physics, University of Ibadan, Nigeria. The values are 20.90BqKg^{-1}, 10.47 BqKg^{-1} and 578.40 BqKg^{-1} respectively for ^{238}U, ^{232}Th and ^{40}K. These values were used for calibrating the spectrometer.

2.4 Hazard index

Radium equivalent activity is widely used to determine the hazard index [8]. The index on the estimation that 370BqKg^{-1} of ^{226}Ra, 4810 BqKg^{-1} and 259 BqKg^{-1} of ^{232}Th produce the same gamma ray dose rate and it is expressed as:

$$R_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (2)$$

The external hazard index as given in table 2 can be defined below:

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (3)$$

3 Results and Discussion

Table 1 shows the range in activity concentration for the natural radionuclides, 7.98 to 228.17BqKg^{-1} for ^{40}K, 3.84 to 170.61BqKg^{-1} for ^{238}U and 0.09 to 78.43BqKg^{-1} for ^{232}Th respectively. The large variation in activity concentrations at different spots could be as a result of mineralogy and drainage pattern of the study area [9]. The spots with high ^{238}U and ^{232}Th, is due to the presence of black sand. Black sand has heavy mineral content such as; zircon, tourmaline, monazite, rutile etc. Sample 4B shows highest concentration in ^{40}K. ^{40}K is known to be high in rock types that are of sedimentary origin. This is because quartzites are made up of fine grains of silky clay and have potassium as an essential constituent ([10], [11],[12],[13],[14]).

The activity concentration of ^{238}U and ^{232}Th was not uniform in the entire study area. The activity concentration of ^{40}K is consistent throughout, except for spot 6 and 10 which show aberration as shown in table 1. This may be due to the presence of feldspar and clay minerals.

Table 1:Activity concentration of Badagry beach sediment samples ($BqKg^{-1}$)

Sample location	Sample code	^{40}K	^{238}U	^{232}Th
1	Sample 1A	156.37 ± 35.17	39.24 ± 18.03	2.02 ± 70.71
	Sample 1B	158.76 ± 35.22	17.91 ± 17.80	3.58 ± 18.32
2	Sample 2A	161.55 ± 35.28	3.84 ± 17.80	2.48 ± 5.65
	Sample 2B	146.79 ± 34.95	14.93 ± 17.63	1.38 ± 39.35
3	Sample 3A	130.84 ± 34.61	87.87 ± 19.32	9.46 ± 34.99
	Sample 3B	164.74 ± 35.36	53.74 ± 18.36	3.58 ± 54.97
4	Sample 4A	124.06 ± 34.47	55.45 ± 18.47	6.34 ± 32.46
	Sample 4B	228.17 ± 36.92	69.52 ± 18.54	0.09 ± 27.36
5	Sample 5A	127.65 ± 34.54	75.50 ± 19.64	20.39 ± 14.89

	Sample 5B	227.37 ± 36.91	25.17 ± 18.07	6.10 ± 13.95
6	Sample 6A	9.97 ± 32.53	69.10 ± 20.40	38.21 ± 8.27
	Sample 6B	9.97 ± 32.53	57.15 ± 21.65	68.21 ± 4.80
7	Sample 7A	198.65 ± 36.17	83.60 ± 19.49	14.51 ± 22.32
	Sample 7B	112.49 ± 34.23	130.09 ± 20.70	18.74 ± 27.02
8	Sample 8A	177.51 ± 35.66	37.96 ± 18.93	19.20 ± 7.89
	Sample 8B	112.29 ± 34.21	60.14 ± 18.66	6.98 ± 32.06
9	Sample 9A	54.25 ± 33.18	112.60 ± 21.53	44.45 ± 12.53
	Sample 9B	188.28 ± 35.91	49.90 ± 18.33	4.22 ± 43.40
10	Sample 10A	7.98 ± 32.51	55.88 ± 19.57	25.90 ± 9.01
	Sample 10B	162.75 ± 35.31	84.45 ± 20.19	28.20 ± 12.11
11	Sample 11A	155.97 ± 35.16	194.50 ± 24.84	78.43 ± 15.39
	Sample 11B	126.45 ± 34.52	76.78 ± 19.34	14.14 ± 20.99
12	Sample 12A	192.27 ± 36.01	100.23 ± 20.72	32.70 ± 13.45
	Sample 12B	159.96 ± 35.25	170.61 ± 23.41	57.68 ± 15.72
13	Sample 13A	197.05 ± 36.13	81.04 ± 19.10	7.80 ± 38.35
	Sample 13B	131.64 ± 34.63	85.31 ± 20.97	43.90 ± 9.28

Table 2: Radium Equivalent and Hazard Index for the Sediment Samples collected From Badagary Beach

Sample	**Radium Equivalent ($BqKg^{-1}$)**	**Hazard Index**
1A	54.17	0.15
2A	19.82	0.05
3A	111.47	0.30
4A	74.06	0.20
5A	114.48	0.31
6A	124.50	0.34
7A	119.65	0.32
8A	79.08	0.21
9A	180.35	0.49
10A	93.53	0.25
11A	318.67	0.86
12A	161.79	0.44
13A	107.51	0.29
1B	35.26	0.010
2B	28.20	0.08
3B	71.55	0.19
4B	87.22	0.24
5B	52.260	0.14
6B	156.29	0.42
7B	165.54	0.45
8B	78.69	0.21
9B	70.44	0.19
10B	137.30	0.37
11B	106.74	0.29
12B	265.41	0.72
13B	158.22	0.43

Table 3:Reduced Data of Heavy Minerals showing Z, T, R and ZTR index

Serial No	Sample No.	Zircon	Tourmaline	Rutile	ZTR (%)	Index
1	Sample 01	6	9	8	53.49	
2	Sample 02	6	4	6	53.33	
3	Sample 03	4	6	9	61.29	
4	Sample 04	6	6	12	55.81	
5	Sample 05	4	6	7	44.74	
6	Sample 06	6	4	12	57.89	
7	Sample 07	4	3	7	46.67	
8	Sample 08	6	4	7	54.84	
9	Sample 09	7	4	5	51.61	
10	Sample 10	5	6	9	58.82	
11	Sample 11	6	6	12	55.81	
12	Sample 12	4	6	7	44.74	
13	Sample 13	6	4	12	57.89	

The radium equivalent and hazard index for the samples gotten from Badagry beach are given above in table 2. The hazard index is used to evaluate the suitability of material for building. The value must be less than unity in order for radiation exposure owing to radioactivity in construction materials to be limited to 1.5mSV/y ([15],[16],[17]).

The result in table 3 shows that the sediments of the study area are marginally mature to immature which are indicated by the presence of Zircon, Tourmaline and Rutile. Zircon occurred as minute, prismatic to rounded colourless grain. They also occurred as inclusions. Tourmaline grains were prismatic greenish brown and are sub-angular to sub-rounded. Rutile grains were yellowish to reddish brown showing adamantine luster in reflected light and occurred mostly in small prismatic crystals. The grains were sub-angular to sub-rounded. Hence, the presence of Zircon, Tourmaline and Rutile (ZTR) is an indication of igneous and metamorphic sources. Base on [18] Hubert (1962), the ZTR index (44.74 – 61.29%) suggest immature to mature sediments.

4 Conclusion

The activity concentrations of ^{40}K, ^{238}U and ^{232}Th are studied and the values have being used to deduce the radium equivalent as well as the hazard index. The values are below the international limit. From the result of this analysis, sand from Badagry beach is suitable for construction of building as it does not pose any significant radiation hazard.

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