EVALUATION OF THE NATURAL RADIOACTIVITY LEVEL OF NIGERIAN TAR SAND DEPOSITS, EASTERN DAHOMEY BASIN, SOUTHWESTERN NIGERIA

by

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The specific activities of natural radionuclides in twenty seven samples collected from the eastern Dahomey basin in southwestern Nigeria were evaluated. Experimental results were obtained by using a 3" 3" sodium iodide NaI(Tl) detector. A major trace element assessment of the samples was made by Inductively Coupled Plasma Mass Spectrometry techniques. Gamma ray radioactive standard sources, ^{137}Cs and ^{60}Co, were used to calibrate the measurement system and the International Atomic Energy Agency SOIL-375 radioactive standard source was also used to analyze and compute the specific activities of desired natural radionuclides. Three radioelements, viz. ^{238}U, ^{232}Th and ^{40}K, were identified in the samples with the following specific activities of ^{238}U ranging from 9.88 4.70 Bq/kg to 69.15 12.37 Bq/kg with an average of 26.50 7.18 Bq/kg; ^{232}Th from 12.78 5.16 Bq/kg to 36.86 13.35 Bq/kg with an average of 22.77 4.28 Bq/kg; ^{40}K ranging from 189.82 79.51 Bq/kg to 518.77 119.54 Bq/kg with an average of 297.69 16.21 Bq/kg. The result was compared with the world mean values of 35, 30 and 400 Bq/kg, respectively, specified by the United Nations Scientific Committee on the Effects of Atomic Radiation. The mean result obtained for the radium equivalent, total absorbed dose rate, external hazard index, internal hazard index, and the annual effective dose equivalent, were 79.90 Bq/kg, 38.50 Sv/h, 0.22 Bq/kg, 0.29 Bq/kg, and 47.22 Sv, respectively. With respect to radiological risk to human health, the absorbed gamma dose rate in air was estimated to be in the range of 21.7 0.4 to 155.7 2.2 Sv/h; the outdoor annual effective dose equivalent was evaluated to vary from 26.6 0.4 to 190.9 2.7 Sv with the arithmetic mean value of 79.06 33.23 Sv and compared to the worldwide effective dose of 70 Sv. Also, the values of the radium equivalent and the external hazard index for all samples in the study area were found to be lower than the accepted safety limit value of 370 Bq/kg and equally below the limit of unity, respectively. The results indicate that, at present, the radiation hazard from radionuclides in all samples analyzed is within permissible limits.

Key words: tar sand, radionuclide, radiation, dose rate, absorbed rate, hazard, environment

INTRODUCTION

Extensive seepages and oil sand exposures are known to occur along the East – West belt stretching over an expanse of 120 km × 6 km across Lagos, Ogun, Ondo, and Edo States in southwestern Nigeria [1], areas within the eastern margin of Dahomey (Benin), a coastal sedimentary basin (fig. 1). Public interest concerning the said resource has necessitated a number of investigations, such as those involving the origin of the tar sands [2] and [3]; geology, oil saturation, reserve estimation and textural characteristics [1, 4, 5]; geochemical and sedimentological characteristics [6-11]; physiochemical properties in relation to production and processing [1, 12, 13], radiogenic components of the deposits [14]. Geological studies and physicochemical properties have confirmed that Nigerian tar sand is an important source of energy and an alternative source of hydrocarbon and raw material for petrochemical industries [15]. However, many factors have hampered the exploitation of this resource and prominent among these is the environmental problem it may pose to the immediate environment and its inhabitants. Radioactive elements occur in trace amounts in most rocks and minerals and are readily detectable by the gamma radiation emitted during their decay [16]. The nature and occurrence of radioactive elements in crude and residual oils is of interest to miners, refinery operators and environmentalists concerned with emissions from oil-fired power plants. The present research is, therefore,

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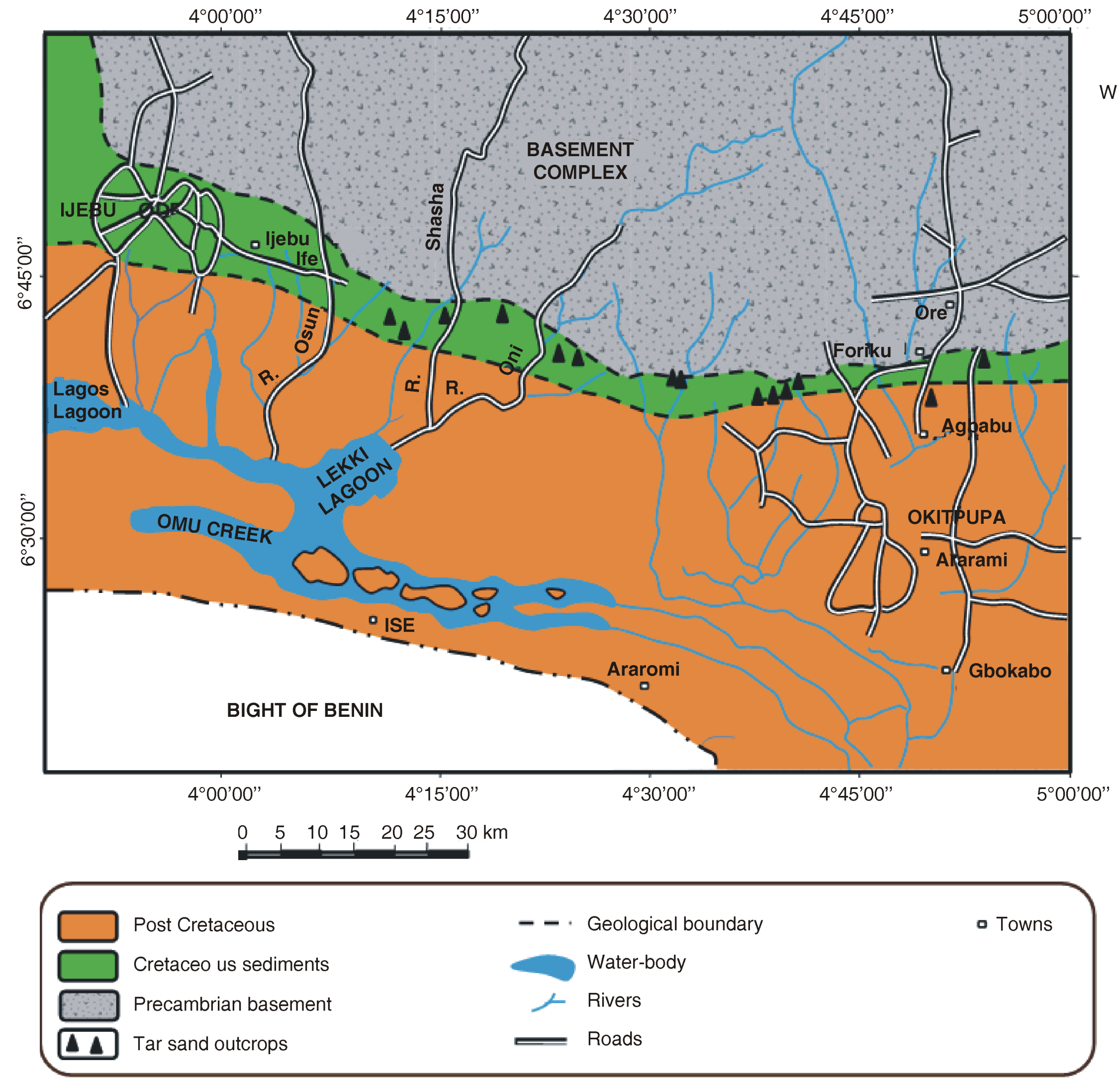

Figure 1. Generalized geological map of the eastern Dahomey basin showing the area extent of tar sand deposits (Modified after [1])

aimed at generating a baseline data on the natural radioactivity level of the tar sand deposits in the eastern Dahomey basin.

GEOLOGY AND STRATIGRAPHY OF THE DAHOMEY BASIN

The Benin (Dahomey) basin is a part of the system of the West African pericratonic (margin sag) basin [17, 18] developed during the commencement of rifting, associated with the opening of the Gulf of Guinea in the Late Jurassic to the Early Cretaceous [19, 20]. The crustal separation, typically preceded by crustal thinning, was accompanied by an extended period of thermally induced basin subsidence through the Middle – Upper Cretaceous to Tertiary times, as the South American and the African plates entered a drift phase to accommodate the emerging Atlantic Ocean [21, 22]. The Ghana Ridge, presumably an offset extension of the Romanche Fracture Zone, confines the basin in the west while the Benin Hinge Line, a basement escarpment which separates the Okitipupa Structure from the Niger Delta basin, confines it in the east. The Benin Hinge Line supposedly defines the continental extension of the Chain Fracture Zone. The onshore part of the basin covers a broad arc-shaped profile of about 600 km^2 in extent. The onshore section of the basin attains a maximum width along its N-S axis of around 130 km in the proximity of the border between Nigeria and the Republic of Benin. The basin narrows to about 50 km on the eastern side where it assumes a convex upwards outline with concomitant thinning of sediments. Along the northeastern fringe of the basin, where it rims the Okitipupa Ridge, tar (oil) sands and bitumen seepages occur [23].

The lithostratigraphic units of the Cretaceous to Tertiary sedimentary succession of the eastern margin of the Dahomey basin, as classified by the Ministry of Solid Minerals [24], are summarized in tab. 1.

Table 1. The stratigraphic column of the dahomey basin, [24]

Formation		Age	Thickness (feet)	Comments
Benin formation Coastal plains sands	Tertiary	Pleistocene – Oligocene	0-1600	Coastal – plain clastics
Oshosun – ilaro – Ameki formations		Eocene	200-1000	Fluvial and marine sands and clays
Ewekoro formation		Palaeocene	400-1000	Marine shale, limestone
Araromi formation Abeokuta formation	Cretaceous	Maastrichtian	500-1000	Coastal sand, shale, marine shale
Afowo formation Turonian Sst Albian Sst		Campanian – Aptian	0-800	Marine sandstone, shale, limestone
Ise formation		Barremian	0-6000+	Continental and lacustrine riftbasin fill
Crystalline basement (undifferentiated)	Cambrian – Precambrian			Metamorphic and igneous complex

SITE DESCRIPTION

The study areas are located within Ogun and Ondo States, approximately within latitudes N 06 38' 54.6" and N 06 46' 47.7 and longitudes E 003 58' 21.4" and E 004 58' 28.57". They are located in the eastern part of the Dahomey basin around the Okitipupa ridge, South-West Nigeria. Their topographies range from relatively low to high reliefs. Imeri-Ijebu, J4, Loda, and Igorisa locations are of low relief, while Orisunmibare, Gbegude, and Idobilayo are areas with a high relief system (8 m-54 m).

The outcrop points are generally sloped and located within farmlands or thick vegetated areas (fig. 2).

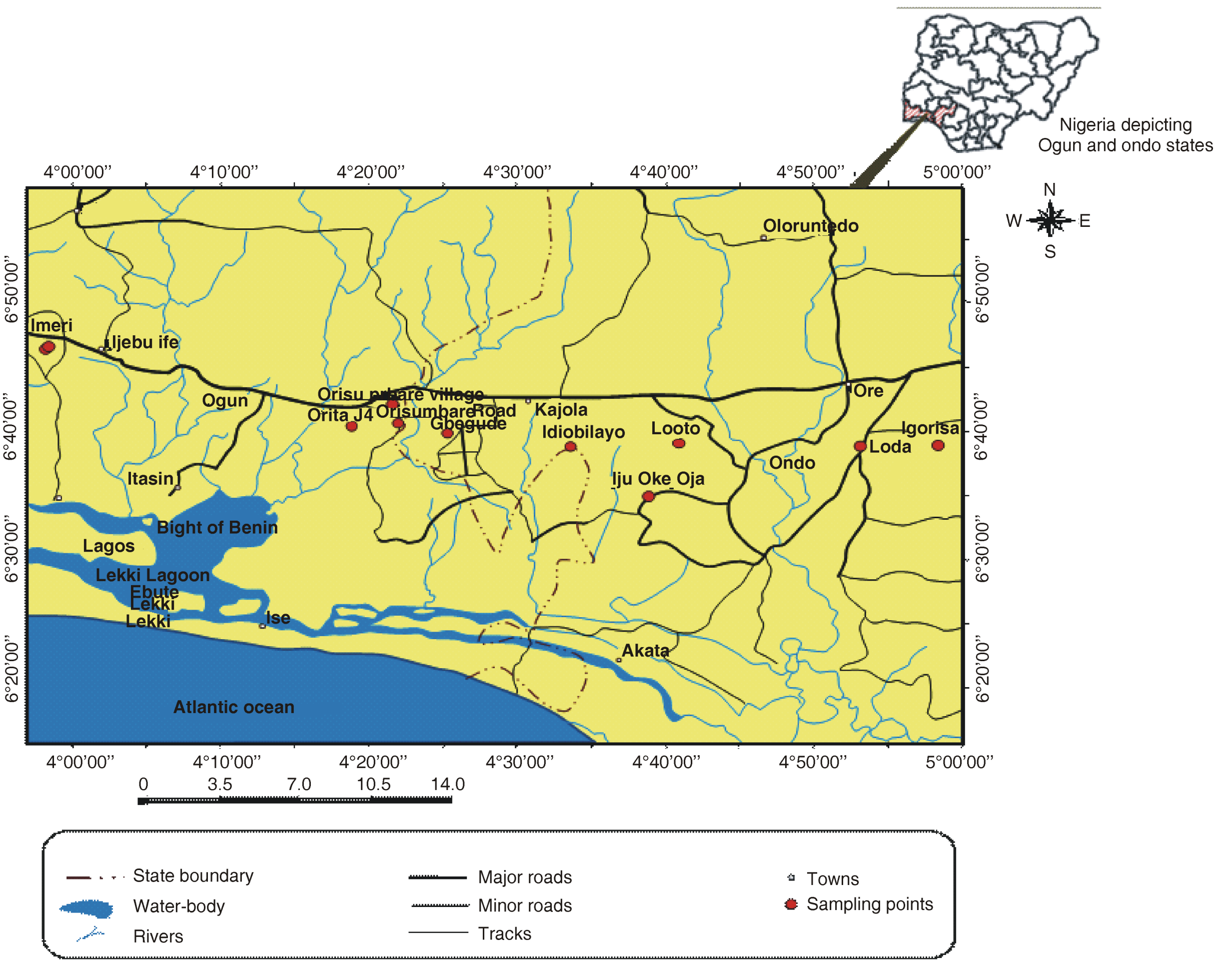

Figure 2. Location map of the study areas

Table 2. Location of sampling points

Sample no	Depth [m]	Name of the town	Brief geology of sampling point	Location	
				Latitude	Longitude
IM1-1	2.0	Imeri-1	Shale	06°46'47.7"	003°58'21.7"
IM1-2	2.5		Shale		
IM1-3	3.0		Shale		
IM2-1	0.5	Imeri-2	Tar sand	06°46'46.2"	003°58'21.4"
IM2-2	1.0		Tar sand		
IM2-3	1.5		Tar sand		
J4 1	0.5	Junction-4 (J4)	Tar sand	06°40'43.6"	004°18'39.4"
J4 2	1.0		Tar sand		
OR1	0.5	Orisumbare	Tar sand	06°42'23.0"	004°21'32.7"
OR2	1.0		Tar sand	06°40'59.4"	004°21'58.4"
GB1	0.5	Gbegude	Tar sand	06°40'04.5"	004°25'14.9"
GB2	1.0		Tar sand		
GB3	1.5		Tar sand		
GB4	2.0		Tar sand		
GB5	2.5		Tar sand		
ID1	0.5	Idobilayo	Tar sand	06°38'54.6"	004°33'39.7"
ID2	1.0		Shale		
ID3	1.5		Shale		
IJ1	0.5	Ijuoke Oja	Lignite	06°35'07.5"	004°38'52.5"
LT1	0.5	Looto	Kaolin	06°34'49.7"	004°40'41.9"
LD1	0.5	Loda	Tar sand	06°39'03.7"	004°53'08.6"
LD2	1.0		Tar sand		
LD3	1.5		Tar sand		
LD4	2.0		Tar sand		
IG1	0.5	Igorisa	Bitumen	06°39'08.7"	004°58'28.6"
IG2	1.0		Bitumen		

METHODOLOGY

Sample collection

The samples were collected at ten different locations across the tar sand belt (from eastern to western parts). Detailed information, as obtained from each sampling location, is indicated in tab. 2.

Laboratory work

Gamma-ray spectrometric analysis was carried out on twenty six samples at the Centre for Energy and Research Development, Obafemi Awolowo University, Ile-Ife, Nigeria. The samples were transferred from bags into clean airtight containers and sealed for twenty eight days so as to attain secular equilibrium and, also, to prevent the escape of Ra-226. Moreover, an empty clean container was weighed and then sealed for a minimum of twenty eight days to serve as the background count. Various detectors have been used to measure the radiation energy deposited in the medium. The choice of the detector for low-counting measurements is a function of many factors, but energy resolution and counting efficiency are the most important ones to be considered. The two types of detectors used in this study are: inorganic scintillation counter sodium iodide (NaI) activated with thalium (Tl), the other one being a high-purity germanium detector (HPGe). After a minimum of twenty eight (28) days for the sealed samples to attain secular equilibrium, the beach sample was placed in a HPGe detector enclosed in a lead shield and counted for ten hours (3600 s). An identical but empty container was sealed for the same twenty eight days and also counted for ten hours. A standard soil sample that contains certified radioactivity concentration due to ^{238}U, ^{232}Th, and ^{40}K by weight was counted for ten hours, as well. The high resolution of the HPGe detector made the identification of a wide spectrum of γ-ray energy in the samples possible and the photopeaks observed with regularity in the samples were identified. The area under each peak of the spectra produced was analysed using a spectra analysis program, SAMPO-90, which matched γ-energies at various energy levels to a library of possible radioisotopes. The background peak height area was subtracted from the standard peak area in order to get the net-peak area values for both the standard and the samplings, respectively.

RESULTS AND DISCUSSION

Radioactivity contents

Natural radionuclide concentrations measured in the samples collected at all locations are as presented in tab. 3.

Table 3. Results of radioactivity concentrations of ^{40}K, ^{238}U, and ^{232}Th series in the samples

Sample	Name of the town	^{40}K	^{238}U(^{226}Ra)	^{232}Th(^{228}Ra)	Dose rate [Svh^{-1}] for	
					Before lab. analysis	After lab. analysis
IM1-1	Imeri-1	419.86 98.37	69.15 12.37	25.55 9.03	0.12	0.12
IM1-2		319.68 106.98	16.57 6.21	17.59 8.73	0.12	0.13
IM1-3		197.89 65.33	18.61 5.31	14.74 5.89	0.10	0.11
IM2-1	Imeri-2	275.78 42.28	48.68 13.16	30.07 12.78	0.12	0.14
IM2-2		207.30 39.33	9.88 4.70	13.19 6.13	0.14	0.13
IM2-3		298.96 53.34	23.28 9.60	25.92 7.35	0.17	0.16
J4-1	Junction-4 (J4)	345.93 88.92	22.42 8.30	25.26 11.09	0.14	0.14
J4-2		362.72 142.58	27.57 10.90	19.34 10.12	0.18	0.17
OR1	Orisumbare	213.30 73.51	14.41 5.36	17.45 7.86	0.12	0.12
OR2		321.24 76.82	17.64 6.41	15.59 4.79	0.10	0.11
GB1	Gbegude	394.65 99.12	47.37 12.54	36.86 13.35	0.15	0.16
GB2		240.09 73.62	23.86 9.62	29.76 9.87	0.17	0.15
GB3		254.98 81.53	21.07 8.23	25.31 8.59	0.16	0.14
GB4		299.77 78.48	26.72 8.86	31.46 7.65	0.18	0.17
GB5		318.19 95.42	32.34 11.09	27.92 11.53	0.20	0.21
ID1	Idobilayo	232.11 58.47	27.83 9.56	28.43 9.80	0.21	0.20
ID2		189.82 79.51	28.33 8.93	15.52 4.15	0.16	0.17
ID3		321.19 77.32	27.04 7.89	19.65 8.54	0.12	0.13
IJ1	Ijuoke Oja	234.78 61.85	28.28 9.65	30.35 9.69	0.15	0.14
LT1	Looto	196.86 59.35	31.14 11.32	12.78 5.16	0.18	0.18
LD1	Loda	340.89 88.91	15.94 7.81	20.90 9.18	0.17	0.16
LD2		282.20 87.74	23.79 8.62	18.06 8.71	0.15	0.15
LD3		362.3 106.85	37.63 7.29	26.43 11.19	0.31	0.28
LD4		343.52 74.77	13.88 6.33	17.55 9.02	0.18	0.17
IG1	Igorisa	518.77 119.54	18.59 6.27	20.42 9.73	0.14	0.15
IG2		324.64 78.91	20.10 9.51	23.31 8.95	0.16	0.15
Average mean value		26.37 8.70	22.70 8.817	298.92 81.04	0.17	0.16

Imeri

At this site, six samples were collected at two different locations. The mean activity concentrations for the various radionuclides were 197.89 65.33 Bq/kg, 9.88 4.70 Bq/kg, and 13.19 6.13 Bq/kg for ^{40}K, ^{238}U and ^{232}Th, respectively. The results indicate that ^{40}K has the highest activity in all samples from Imeri, with the highest value of ^{238}U being 69.15 12.37 Bq/kg. The Imeri- 1(IM1-1) has the highest value of ^{40}K (419.86 98.37 Bq/kg). ^{232}Th recorded the lowest average radionuclide value of 21.18 8.32 Bq/kg (fig. 3).

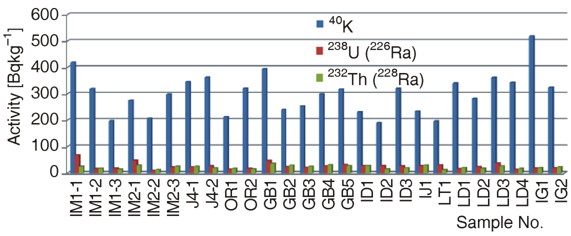

Figure 3. Pictorial representation of ^{40}K, ^{238}U, and ^{232}Th in all samples

J4

The radionuclides identified at J4 with the highest activity concentration belong to the decay series of ^{40}K, with an average specific activity concentration of 354.33 115.75 51 Bq/kg which shows an increase with depth. ^{238}U and ^{232}Th displayed a considerably lower value, as shown in fig. 3.

Orisumbare

^{232}Th and ^{238}U have the least contribution to the total activity of the samples collected at Orisumbare, with concentration ranging from 17.45 7.86 to 15.59 4.79 and 14.41 5.36 to17.64 6.41 Bq/kg, respectively. The K-40 radionuclide has the highest activity with a value of 213.30 73.51 Bq/kg and 321.24 76.8251 Bq/kg (fig. 3). The radioactive nuclides in samples collected at this location displayed a relative increase in radionuclide concentration with depth, with the exception of those of the ^{232}Th series.

Gbegude

Gbegude is characterised by a range of values of activity concentration, as recorded in all six samples collected at this location. For all of the six samples collected at Gbegude, the radionuclide concentration varies between 220.11 79.13 and 394.65 99.12 Bq/kg with an average of 287.97 84.55 Bq/kg for ^{40}K; 21.07 8.23 and 47.37 12.54 Bq/kg with an average of 29.12 9.92 Bq/kg for ^{238}U; 25.31 8.59 and 36.86 13.35 Bq/kg with an average of 29.45 10.03 Bq/kg for ^{232}Th. ^{40}K has the highest concentration of the three radionuclides present (about 82 % of the total activity).

Idobilayo

Three samples were collected at Idobilayo at various depths (tab. 3). For ^{40}K concentration, Idobilayo 3 (ID3) has the highest value of 321.19 77.327 Bq/kg, while the lowest value of 232.11 58.47 Bq/kg was found at Idobilayo 1 (ID1). ^{238}U concentrations have a slight value variance with an average value of 27.72 8.79 Bq/kg, as shown in fig. 3. The highest value of Th-232 is at Idobilayo 2 (ID2) with a value of 28.43 9.80 Bq/kg. Generally, the concentration of ^{40}K was relatively higher compared to concentrations of ^{238}U and ^{232}Th in all of the analyzed samples.

Ijuoke oja

The ^{40}K activity concentration of the lignite sample at this location has an average value of 234.78 61.85 Bq/kg. ^{238}U and ^{232}Th had a value of 28.28 9.65 Bq/kg and 30.35 9.69 Bq/kg which is considerable for the average range, compared to the activity concentration recorded at other locations, as shown in fig. 3.

Looto

The pictorial representation of radionuclide concentration values obtained at Looto is shown in fig. 3. Looto is characterized by a relative low value of the activity concentration with 196.86 59.35 Bq/kg, 31.14 11.32 Bq/kg, and 12.78 5.16 Bq/kg for ^{40}K, ^{238}U and ^{232}Th, respectively. The value of ^{40}K is high compared to the value that was obtained for ^{238}U and ^{232}Th which is the general trend at all other locations.

Loda

The specific activities measured in the various samples collected at Loda are shown in fig. 3. The activity concentration of ^{40}K ranged from 340.89 88.91 Bq/kg to 282.20 87.74 Bq/kg with an average of 332.22 89.57 Bq/kg; 13.88 6.33 Bq/kg to 37.63 7.29 Bq/kg with an average of 22.81 7.51 Bq/kg for ^{282}U; 17.55 9.02 Bq/kg to 26.43 11.19 Bq/kg with an average of 20.74 9.53 Bq/kg for ^{232}Th. The largest contribution to the overall activity in all of the various samples collected at Loda was mainly from ^{40}K, with the lowest value of 282.20 87.74 Bq/kg, the highest being 340.89 88.91 Bq/kg compared to the average activity ranges of 22.81 7.51 Bq/kg and 20.74 9.53 Bq/kg for ^{238}U and ^{232}Th, respectively. The specific activity due to ^{232}Th is relatively low in all samples investigated at this location.

Igorisa

^{40}K is the highest contributor to the activity in the area covering about 93 % of the total activity concentrations, while ^{238}U and ^{232}Th contribute by 3 % and 4 %, respectively. In the specimen, the activity of ^{238}U is the lowest in comparison to that of ^{232}Th and this consistency is reflected in the samples collected at the location (see fig. 3).

From fig. 3, it was obvious that the sample collected at Igorisa 1(IG1) has the highest concentration of ^{40}K, the highest concentration of ^{238}U was recorded at Imeri 1(IM1-1), while the highest concentration of ^{232}Th was observed at Gbegude1(GB1).

According to Serra-2008 [25], it was asserted that illite is the primary potassium-bearing mineral in oil sands. This is followed by K-feldspar, while muscovite and biotite are minor phases. Akinmosin *et al.*, 2011 [26] identified the presence of K-feldspar as one of the components of the Nigerian tar sand deposits by scanning the electron microscope images of some samples. Moreover, from the petrographic study of some tar sand samples from the Nigerian tar sand belt, Akinmosin *et al.*, 2005 [27] established that micas are present in traces. Based on this premise, it is safe to adduce that the higher values of radioactive concentration of ^{40}K recorded in all cited locations over other radionuclides can be said to have been sourced from the K-feldspar component of the deposit. K-feldspar usually occurs in the form of inclusions within the tar sand deposit. Uranium and thorium may have been derived from radioactive minerals such as zircon, xenotime, and possibly, thorite [28].

Absorbed dose rate in samples

Two different records of the absorbed dose rate in the samples were taken: before the laboratory analysis and after the analysis was carried out using a Gamma-Scout detector. The results of the total absorbed dose rate in the twenty six samples collected are summarized in tab. 3. It varies between 0.1-0.21 μSv/h, averaging 0.16 μSv/h before the laboratory analysis. After the analysis, the value varied from 0.11-0.28 μSv/h, the average dose rate being 0.16 μSv/h. Sample LD3 collected at Loda had the highest dose rate with the absorbed dose rate of 0.31μSv/h and 0.28 μSv/h before and after the laboratory analyses (figs. 4 and 9). This sample also recorded the highest values in activity concentration of all for the radionuclides identified at said locations.

Radiological effects, indices and hazard assessment

One of the main objectives of radioactivity measurement in environmental studies is not to simply determine the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K, but also to estimate the radiation exposure dose and assess the biological effects on humans. The assessment of radiological risk can be considered in various terms. In the current study, five related quantities were deduced. These include:
(1) Radium equivalent activity (Ra_{eq}), (2) Absorbed dose rate (D), (3) Annual effective dose equivalent (AEDE), (4) External hazard index (H_{ex}), and (5) Internal hazard index (H_{in}).

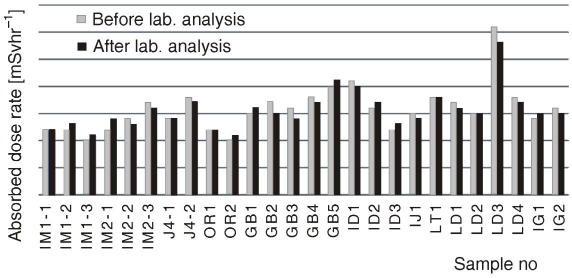

Figure 4. Pictorial representation of the absorbed dose rates from gamma radiation

These radiological parameters can be calculated from the measured activity concentrations of the three main primordial radionuclides in the samples. The values of these radiological hazard parameters, as deduced in the current work, are shown in tab. 4.

Radium equivalent activity

The calculated value of radium equivalent activity is shown in tab. 4. The mean Ra_{eq} ranges between 43.25 and 135.08 Bq/kg with an average value of

Table 4. Radium equivalent activity, dose rate, annual effective dose, external hazard index and internal hazard index at different locations in the study area

Samples	Radiological indices				
	Radium equivalent activity [Bqkg^{-1}]	Dose rate [nGyh^{-1}]	Annual effective dose [μSv]	External hazard index	Internal hazard index
IM1-1	135.08	65.01	79.73	0.37	0.56
IM1-2	64.1	31.71	38.88	0.18	0.22
IM1-3	53.54	25.81	31.66	0.15	0.2
IM2-1	110.98	52.24	64.06	0.31	0.44
IM2-2	43.25	21.24	26.05	0.12	0.15
IM2-3	81.27	38.97	47.79	0.23	0.29
J4-1	82.76	40.14	49.23	0.23	0.29
J4-2	80.62	39.65	48.63	0.22	0.3
OR1	54.29	26.16	32.08	0.15	0.19
OR2	62.42	31.06	38.09	0.17	0.22
GB1	127.71	60.72	74.47	0.35	0.48
GB2	83.22	39.08	47.93	0.23	0.29
GB3	75.11	35.73	43.82	0.21	0.26
GB4	92.69	43.94	53.88	0.26	0.33
GB5	94.54	45.17	55.39	0.26	0.35
ID1	84.73	39.78	48.78	0.23	0.31
ID2	63.81	30.43	37.33	0.18	0.25
ID3	77.62	37.85	46.42	0.22	0.29
IJ1	88.12	41.26	50.60	0.24	0.32
LT1	63.2	30.37	37.25	0.17	0.26
LD1	69.69	34.31	42.07	0.19	0.24
LD2	69.37	33.75	41.39	0.19	0.26
LD3	100.79	48.57	59.56	0.28	0.38
LD4	63.02	31.44	38.56	0.18	0.21
IG1	84.1	42.71	52.38	0.24	0.29
IG2	76.16	37.00	45.38	0.21	0.27
Range	43.25-135.08	21.24-65.01	26.05-79.73	0.12-0.37	0.15-0.56
Average	79.90	38.50	47.22	0.22	0.29
World mean range [29]	<370	57 18-93	70 –	<1	<1

79.90 Bq/kg. The highest value of Ra_{eq} was observed in Imeri tar sand samples denoted IM1-1, while the lowest values are seen at the same location (Imeri). This location is characterized with the highest and lowest value of ^{238}U radionuclide concentration, hence, the entire value of Ra_{eq} falls below the desirable limit. Figure 5 is a graphical representation of the radium equivalent activity.

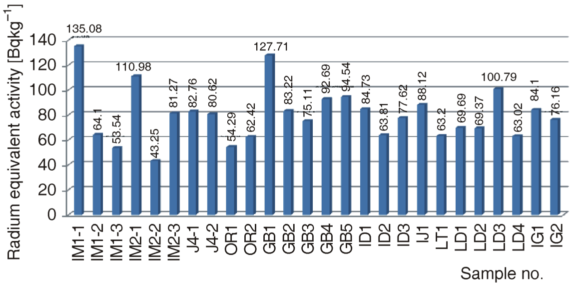

Figure 5. Graphical representation of radium equivalent activity

Total absorbed dose rate

The total absorbed dose rates calculated for all samples collected are shown in tab. 4. The value of the total mean absorbed dose rate at 1.0 m above the ground level ranges from 21.24-65.00 μSv/h with an average of 38.5 μSv/h. The highest value was recorded at Imeri, which is relatively small when compared with the value (1.0 mSv per year) recommended by the International Commission on Radiological Protection as the maximum permissible dose equivalent for members of the public. This implies that the tar sand in the study areas is safe for mining and human activities. Figure 6 is a graphical representation of the dose rate.

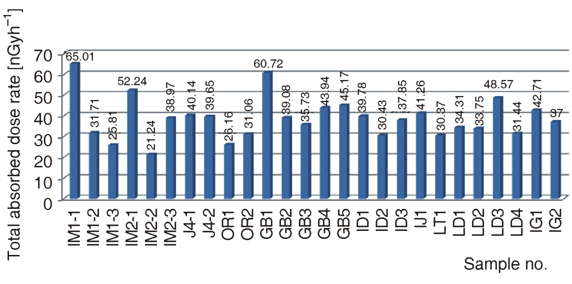

Figure 6. Graphical representation of the total absorbed dose rate

External hazard index

The result presented in tab. 4 shows that the mean H_{ex} ranged between 0.12 and 0.3 with an average value of 0.22. These values, being less than 1 as recommended by the International Commission on Radiological Protection, show that the samples are safe for exposure to human activities. Figure 7 is a graphical representation of the H_{ex}.

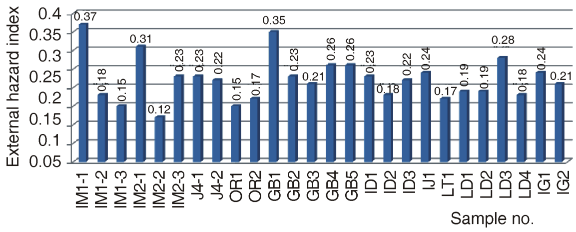

Figure 7. Graphical representation of the externa hazard index

Internal hazard index

The values obtained for the internal hazard index are as shown in tab. 4, demonstrating that the mean H_{in} ranged from 0.15 to 0.56 with an average of 0.29.The internal hazard index (H_{in}) of the study area is <1 (maximum value recommended by [30]). This implies that the radiation in the study area is below the recommended H_{in}, as shown in fig. 8.

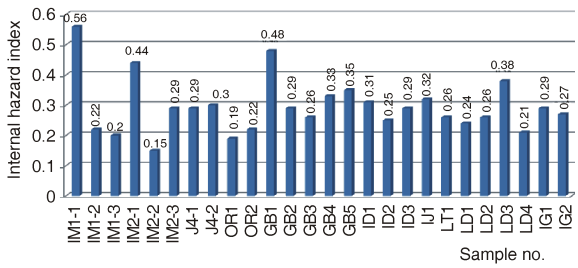

Figure 8. Graphical representation of the internal hazard index

Annual effective dose

As shown in fig. 9 the annual effective dose was found to vary between 26.05 and 79.73 μSv with a mean of 47.22 μSv (tab. 4). Two of the locations, (Imeri – IM1 and Gbegude – GB1), show a slightly higher value than the world average.

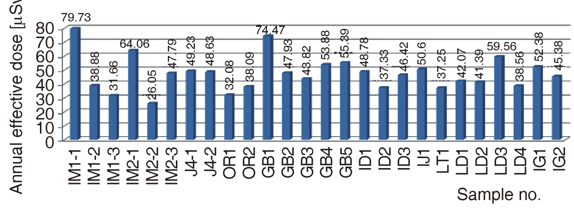

Figure 9. Graphical representation of the annual effective dose

CONCLUSIONS

The level of natural radioactivity in samples collected along the tar sand belt in the eastern Dahomey basin has been evaluated via a 3" × 3" sodium iodide NaI(Tl) detector. The results of the investigation showed that primordial radionuclides, namely ^{238}U,

^{232}Th, and ^{40}K, were present in all samples. The measured activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in all of the samples collected varied from 9.88 4.70 Bq/kg to 69.15 12.37 Bq/kg, 12.78 5.16 Bq/kg to 36.86 13.35 Bq/kg, and 189.82 79.1 Bq/kg to 518.77 119.54 Bq/kg, with the average mean values of 26.37 ± 8.70 Bq/kg, 22.70 ± 8.817 Bq/kg, and 298.92 ± 81.04 Bq/kg, respectively. The results obtained for activity concentrations of ^{238}U and ^{232}Th were found to be lower than the upper range of the worldwide values of 17-60 Bq/kg, 11-64 Bq/kg identified by UNSCEAR-2000 [31]. The activity concentration of ^{40}K in the study area falls within the worldwide range of values which are 140-850 Bq/kg, as reported by Oladunjoye *et al*., – 2014 [28]. The highest contributor of ^{40}K came from the bitumen samples at Igorisa, while that of ^{238}U was from the tar sand samples at Imeri and Gbegude with the highest value of ^{232}Th detected. The Kaolin sample collected from Looto has the lowest value of ^{232}Th. In all sampled locations, the mean activity concentration is of the order ^{232}Th < ^{238}U < ^{40}K. Generally, the concentration of ^{232}Th is lower than that of ^{238}U and ^{40}K, respectively. ^{40}K activity dominates over ^{238}U and ^{232}Th elemental activities, possibly due to the richness of the tar deposits in K-feldspars. The average value of the absorbed dose rate of collected samples is lower than the world average value. On the basis of lower levels of natural radioactivity, the study area can be considered as having a less natural background radiation area. Consequently, at present, it can be concluded that the study area poses no immediate environmental threat to its inhabitants.

AUTHORS' CONTRIBUTIONS

The field work exercise and the laboratory studies were carried out by all authors. The manuscript write up was carried out by A. Akinmosin and proof read by M. A. Oladunjoye. Bulk of the figures was drawn by M. A. Oladunjoye while the tables and some of the plottings were done by F. Essien.

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ПРОЦЕНА НИВОА ПРИРОДНЕ РАДИОАКТИВНОСТИ У НАСЛАГАМА КАТРАНА У БАСЕНУ ИСТОЧНОГ ДАХОМЕЈА У ЈУГОЗАПАДНОЈ НИГЕРИЈИ

У овом раду процењена је специфична активност природних радионуклида из двадесет седам узорака сакупљених у басену у источном Дахомеју у југозападној Нигерији. За добијање експерименталних резултата коришћен је 3" 3" натријум-јодидни (NaI(Tl))детектор, а применом технике индуктивно спрегнуте плазме и масене спектрометрије праћени су жељени елементи. Као стандардни извори гама зрачења за калибрацију система за мерење употребљени су цезијум (^{137}Cs) и кобалт (^{60}Co), а SOIL-375, радиоактивни стандардни извор Међународне агенције за атомску енергију примењен је за анализу и прорачун специфичних активности жељених природних радионуклида. Три радионуклида, ^{238}U, ^{232}Th и ^{40}K, идентификована су у узорцима, а њихове специфичне активности су: за ^{238}U, од 9.88 4.70 Bq/kg до 69.15 12.37 Bq/kg, са средњом вредношћу од 26.50 7.18 Bq/kg, за ^{232}Th, од 12.78 5.16 Bq/kg до 36.86 13.35 Bq/kg, са средњом вредношћу од 22.77 4.28 Bq/kg, и за ^{40}K,од 189.82 79.51 Bq/kg до 518.77 119.54 Bq/kg, са средњом вредношћу од 297.69 16.21 Bq/kg. Резултати су упоређени са средњим вредностима у свету од 35 Bq/kg, 30 Bq/kg и 400 Bq/kg, респективно, које су наведене од стане Научног комитета за ефекте атомског зрачење Уједињених Нација. Средње вредности еквивалента радијума, тоталне апсорбоване јачине дозе, индекса спољашњег хазарда, индекса унутрашњег хазарда и годишњег ефективног дозног еквивалента су 79.90 Bq/kg, 38.50 Sv/h, 0.22 Bq/kg, 0.29 Bq/kg и 47.22 μSv, респективно. Водећи рачуна о радиолошком ризику за људско здравље процењена је апсорбована јачина гама зрачења у ваздуху у опсегу 21.7 0.4 Sv/h до 155.7 2.2 Sv/h, а за спољашњи годишњи ефективни дозни еквивалент резултати су били у опсегу од 26.6 0.4 Sv до 190.9 2.7 Sv са средњом вредношћу од 79.06 33.23 Sv, у поређењу са ефективном дозом у свету од 70 Sv. Такође, вредности еквивалента радијума и индекса спољашњег хазарда свих узорака, ниже су од прихваћене граничне вредности од 370 Bq/kg и испод вредности јединице, респективно. Резултати показују да је у овом тренутку ризик од радионуклида на основу анализираних узорака у дозвољеним границама.

Кључне речи: катран, радионуклид, зрачење, јачина дозе, апсорбована доза, ризик, животна средина