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Ochradioecological Assesment of the Sediment of Kainji Lake Due to Natural Radionuclides

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Abstract: A study is conducted for natural radioactivity in the sediment of Kainji Lake, Niger state, Nigeria, using gamma spectroscopy with Na(Tl) detector. Sediment of the lake is analyzed to estimate the activity concentration due to natural radionuclides (^{226}Ra, ^{232}Th and ^{40}K). The study shows that the activity concentration values for the collected sediments are within the acceptable limit. Most of the values obtained are lower than the world's average values. The range of the values obtained is 4.64±1.00 Bqkg^{-1} to 52.14±4.30 Bqkg^{-1} for ^{226}Ra, 6.84±0.01 to 46.76±1.14 Bqkg^{-1} for ^{232}Th and 43.7±4.32 Bqkg^{-1} to 202.28±5.45.00 Bqkg^{-1} for ^{40}K. Likewise the annual effective dose and external and internal hazard index was estimated. However the results for sediments activity shows very lower values. Although radioactivity measured in lakes is usually higher than that of flowing river waters, because a significant part of the radioactive substance brought in by other tributary rivers accumulates in it, [1]. This study shows Kainji Lake sediment has low activity, since the lake is a flowing lake that gets recharge throughout the year.

Key words: Radioactivity · Dose · Radionuclides

INTRODUCTION

Natural radioactivity is the major contributor to ionizing radiation in environment. It comes from both natural background and man-made sources. Naturally abundant radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in the environment and releases from fertilizers, agrochemicals, research and medical facilities forms the bulk of radionuclides in ground and surface water, [2]. Therefore presence of radioactivity in contaminated environment can be attributed to naturally occurring and or artificially induced sources. Naturally occurring radioactivity are due to bedrock formations which are weathered, resulting in mineral leaching that leads to contamination, [3]. Artificial radioactivity is due to human activities. Contaminations are mainly as a result of agriculture, medicine, research as well as other activities like mining and milling of mineral ore which exposes the earth surface. All this contamination may have health effect; that poses great danger to human and other living organism in the biosphere. Due to this reason, the radio-ecological assessment and protection of water resources, water quality and biosphere is critical for global human and environmental safety.

MATERIALS AND METHODS

Area of Study and Location: Lake Kainji is situated between latitudes 9° 50' - 10° 57' North and longitudes 4° 25' - 4° 45' East. The Lake was impounded on 2nd August 1968 and it is 136.8 km in length and 24.1 km maximum width. Its surface area has been variously quoted as approximately 1,300 km^2. At full volume, the water is at the altitude 142 m and at low volume the water is at the 133 m level, [4]. The Lake, which is surrounded by many fishing communities; resulted from the damming of the River Niger is the largest artificial Lake in Nigeria and is well known for recreation irrigation and fishing. Apart from hydropower generation it received thousands of visitors and tourist yearly due to the fact that it is situated within the Nigeria's first game reserve.

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Ten locations were selected from the already established study stations on the lake, with seven points from the upstream and three points downstream of the lake for the study.

Samples Collection: The study on the lake for natural radioactivity was based on the accepted guideline permissible and adopted by the International Commission on Radiological Protection (ICRP), the National Committee on Radiation Protection and Measurements (NCRP), (FRC), (IAEA).

Samples of Lake's sediments were collected at an approximate depth of 3 metres minimum to 24 metres maximum from the upstream and downstream of the lake at random from 10 reference points for the analysis. This was done using Ickmang grab device (Bureau technique Wintgen (BEW) Eupen/Belgium). They were carefully put into different polyethylene bags, labelled and the exact position noted using GPRS device. The sediments were kept opened to dry at ambient temperature at laboratory in a clean environment, which were later carefully packed into polyethylene bags and transported to the Centre for Energy Research and Training, Zaria for further preparation, Gamma spectroscopy count and analysis in accordance with IAEA and ISO method.

Samples Preparation for Gamma Spectrometry: The sediments were grounded to fine powder and packed into fill labelled cylindrical plastic containers of height 7cm by 6cm diameter. This satisfies the selection of optimal sample container height [5]. Each container accommodated approximately 300.0g of sample. They were carefully sealed (using Vaseline, candle wax and masking tape) to prevent radon escape and store for a minimum of 30 days. This was to allow the radium attain equilibrium with its daughters in accordance with Ramasamy, *et al.* [6].

Gamma Spectrometry Method Analysis: Gamma spectrometry is a widely used analytical method that depends on one of the physical properties of most radionuclides, namely the emission of gamma rays, when the radionuclides decay. It has seen many applications in natural environmental studies, especially when it comes to study of radioactive ores. The main advantage of the method resides in the cheapness, speed of analysis relative ease of sample preparations and simplicity of data reduction. The radioactive chain of uranium and thorium includes daughter isotopes that emit gamma rays of characteristic energy level. In gamma spectrometry, the spectra from natural (un-irradiated) samples are measured to determine the bulk uranium, thorium and potassium content of the sample. The measuring device for the study is NaI(TI) detector.

Samples Activity Acquisition and Analysis in Gamma Spectrometry: The prepared samples were mounted on the detector surface and each was counted for 29,000 seconds in reproducible sample-detector geometry. The configuration and geometry was maintained throughout the analysis. A computer program from ORTEC was used for data acquisitions and analysis of gamma spectra. The 1764keV γ-line of ^{214}Bi for U was used in assessment of the activity concentration of ^{226}Ra while 2614.5keV γ-line of ^{208}Tl was used for ^{232}Th. The single 1460keV γ-line of ^{40}K was used in evaluation of ^{40}K.

Activity Concentration: The activity concentrations in the samples were obtained using the equation 1 [7, 8]

$$C(BqKg)^{-1} = kC_n \quad (1)$$

where $k = \frac{1}{\varepsilon P_\gamma M_S}$, C is the activity concentration of the radionuclide in the sample given in Bqkg^{-1}, C_n is the count rate under the corresponding peak, ε is the detector efficiency at the specific γ-ray energy, P_γ is the absolute trasnsition probability of the specific γ-ray and M_s is the mass of the sample (kg). The below detection limit (BDL) of a measuring system describes its operating capability without the influence of the samples. The BDL given in Bqkg^{-1} which is required to estimate the minimum detectable activity in samples was obtained using equation (2), [8].

$$DL(Bqkg^{-1}) = 4.65\frac{\sqrt{C_b}}{t_b}k \quad (2)$$

where C_b is the net background count in the corresponding peak, t_b is the background counting time (s) and k is the factor that converts counts per second (cps) to activity concentration (Bqkg^{-1}) as given in equation 1.

All the obtained raw data were converted to convectional units using conversion factors of 8.632x10^{-4}, 8.768x10^{-4} and 6.431x10^{-4} for ^{40}K, ^{226}Ra and ^{232}Th respectively to determine their activity concentrations. With the counting time of 29,000 seconds for each sample, the environmental γ-ray background of the laboratory site was determined using an empty container under identical measured conditions. This then gave the below detectable

limit (BDL) limits to be 310.99 BqKg^{-1} for ^{40}K, 16.21 BqKg^{-1} for ^{226}Ra and 123.16 BqKg^{-1} ^{232}Th respectively. This was subtracted from the measured γ-ray spectrum of each sample.

Calculation of Absorbed Dose Rate from Measured Activity Concentrations of Sediments: Radiation emitted by a radioactive substance is absorbed by any material it encounters. [9] has given the dose conversion factors for converting the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K into dose (nGyh^{-1} per Bqkg^{-1}) as 0.427, 0.662 and 0.043, respectively [9]. Using these factors, the total absorbed dose rate in air is calculated as given in the Equation 3 [9].

$$D = (0.427C_{Ra}+0.662C_{Th} + 0.043C_K)\ nGyh^{-1}, \quad (3)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations (Bqkg^{-1}) of radium, thorium and potassium, respectively in the samples.

Calculation of Annual Effective Dose from Sediment: The estimation of the annual effective dose rates, depended on conversion coefficient from absorbed dose to effective dose, 0.7 SvGy^{-1} and outdoor occupancy factor of 0.2 as proposed by (UNSCEAR, 2000) [9]. The effective dose rate in units of mSvGy^{-1} was calculated by the following formula in equation 4.

$$\text{Effective dose rate (mSvGy}^{-1}) = D\ (nGyh^{-1}) \times 8760h \times 0.2 \times 0.7SvGy^{-1} \times 10^{-6} \quad (4)$$

External Hazard Index (Hex): Radiation exposure due to ^{226}Ra, ^{232}Th and ^{40}K may be external. This hazard, defined in terms of external hazard index or outdoor radiation hazard index and denoted by H_{ex}, can be calculated using the equation 5, [10]:

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (5)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations (Bqkg^{-1}) of radium, thorium and potassium, respectively as obtained in the analyzed samples. The value of this index should be less than 1 *m*Svy^{-1} in order for the radiation hazard to be considered acceptable to the public.

Internal Hazard Index (H_{in}): The internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon and is given by equation 6, [10]:

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (6)$$

The value of this index should be less than 1 mSvy^{-1} in order for the radiation hazard to have negligible hazardous effects to the respiratory organs of the public [10].

RESULT AND DISCUSION

The spectra that were generated from samples during spectrometric analysis were used in identification of the radionuclides in the samples. This has made it possible to have a comprehensive activity concentration in (Bqkg^{-1}) of ^{232}Th, ^{226}Ra and ^{40}K for the sediments collected at various locations.

Activity Concentration in Sediments: The results of analysis of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in lake sediment samples for different locations of the study area are presented in Table 1. The activity is reported in Bqkg^{-1} on the basis of the sediment's dry weight, calculated using equation 1. The measured activity concentrations range from 4.64±1.00 Bqkg^{-1} to 52.14±3.47 Bqkg^{-1} for ^{226}Ra, 6.84±0.01 Bqkg^{-1}to 46.76±1.14 Bqkg^{-1} for ^{232}Th and 43.7±4.32 Bqkg^{-1} to 202.28±5.45 Bqkg^{-1} for ^{40}K.

The average activity concentration in the sediments as presented in the table was 19.23±1.85, 31.59±21.02 and 84.12±2.64 Bqkg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively. These is higher when compared to what was obtained during assessment of terrestrial sediments in Nigerian delta region with 16 Bqkg^{-1}for ^{238}U, 24 Bqkg^{-1} for ^{232}Th and 35 Bqkg^{-1} for ^{40}K, [11]. Although the obtained values from the activity of these sediments were less than the world average values for sediments; 32 Bqkg^{-1}, 45 Bqkg^{-1} and 420 Bqkg^{-1} ^{226}Ra, ^{232}Th and ^{40}K respectively, [9].

Absorbed Dose Rate, Annual Effective Dose Equivalent, External Hazard and Internal Hazard Index for Sediment: The absorbed dose rates due to terrestrial gamma rays at 1 m above ground for the activity concentration from ^{226} Ra, ^{232}Th and ^{40}K in the sediments were obtained and calculated using equation (3). Table 2 present the dose rate, effective dose equivalent and external and internal hazard indexes form all the sediments. The absorbed dose values ranges from 10.12nGyh^{-1} to 48.45nGyh^{-1} with an average of 32.75nGyh^{-1}. This is within the worldwide value range which is from 18nGyh^{-1} to 93nGyh^{-1} and the average absorbed dose rate is less than the average worldwide population weight value from absorbed dose rate in outdoor air, 43nGyh^{-1} [9].

Table 4.1: Total Activity concentration for Sediment Sample

S/No.	Sample ID	Activity in Bqkg^{-1} Ra-226	Activity in Bqkg^{-1} Th-232	Activity in Bqkg^{-1} K-40	Total Activity in BqKg^{-1}
1	Upsteam01	52.14±3.47	37.64±0.01	29.54±3.11	119.32±6.59
2	Upsteam02	28.97±4.63	26.23±1.14	136.84±3.11	192.04±8.88
3	Upsteam03	13.9±2.32	33.07±2.2	94.85±1.55	141.82±6.07
4	Upsteam04	31.28±1.15	41.06±1.14	54.42±3.11	126.76±5.40
5	Upsteam05	8.11±1.20	43.34±1.14	150.83±3.11	202.28±5.45
6	Upsteam06	9.27±1.20	15.97±1.14	63.75±4.66	88.99±5.67
7	Upsteam07	4.64±1.00	38.78±1.14	105.74±0.01	149.16±2.15
8	Downstream01	10.43±1.20	6.84±0.01	26.43±3.11	43.7±4.32
9	Downstream02	17.38±1.20	46.76±1.14	73.08±0.01	137.22±2.35
10	Downstream03	16.22±1.16	26.23±1.14	105.74±4.66	148.19±6.96
	Average	19.23±1.85	31.59±21.02	84.12±2.64	134.95±5.52
	Max	52.14±3.47	46.76±1.14	150.83±3.11	202.28±5.45
	Min	4.64±1.00	6.84±0.01	26.43±3.11	43.7±4.32

Table 2: Absorbed dose and hazard index in Sediment

		Sample Location					
S/No	Sample ID	Lon	Lat	Absorbed dose rate (nGyh^{-1})	Effective dose rate (mSvy^{-1})	External hazard index H_{ex}	Internal hazard index H_{in}
1	Upsteam01	9°51'.485"N	4°35'.473"E	48.45	0.060	0.29	0.43
2	Upsteam02	9°51'.285"N	4°35'.533"E	35.62	0.044	0.21	0.29
3	Upsteam03	9°51'.722"N	4°34'.424"E	31.91	0.040	0.20	0.22
4	Upsteam04	9°54'.102"N	4°33'.942"E	42.88	0.053	0.25	0.34
5	Upsteam05	NIL		38.64	0.047	0.22	0.24
6	Upsteam06	NIL		17.28	0.021	0.10	0.13
7	Upsteam07	9°57'.638"N	4°32'.415"E	32.20	0.039	0.20	0.20
8	Downstream01	9°51'.337"N	4°37'.054"E	10.12	0.012	0.06	0.09
9	Downstream02	9°51'.369"N	4°36'.952"E	41.52	0.051	0.24	0.29
10	Downstream03	9°51'.797"N	4°36'.849"E	28.84	0.035	0.17	0.21
	Average			32.75	0.040	0.19	0.24
	Max			48.45	0.060	0.29	0.43
	Min			10.12	0.012	0.06	0.09

The effective annual dose rate due to these radionuclides in the sediments was also obtained from equation (4) and the values ranges from 0.012mSvy^{-1} to 0.060mSvy^{-1} with an average value of 0.040mSvy^{-1}. This is also less than the average annual dose limit set for radiological assessment which is 1mSvy^{-1}.

The external (H_{ex}) and internal (H_{in}) hazard indexes, which represent the risk associated from exposure these radionuclides in the sediments was calculated using equation (5) and (6). The results as presented has a (Min. of 0.06, Max. 0.29 with an overall average value of 0.19) and (Min. of 0.09, Max. of 0.43 and average of 0.24) for the external and internal hazard index respectively. This indicated that the risk associated with sediments sample is quite below the limit set by [12] for radiological exposure protection to the public which is unity [12]. However care has to be taken since it is believed that radiation at any given level poses a risk.

CONCLUSION

The activity concentration value obtained for the sediments in this study were found to be within the acceptable limits. Most of the values obtained were lower than the world's average values. The range of the values obtained are 4.64±1.00 Bqkg^{-1} to 52.14±4.30 Bqkg^{-1} for ^{226}Ra, 6.84±0.01 to46.76±1.14 Bqkg^{-1} for ^{232}Th and 43.7±4.32 Bqkg^{-1} to 202.28±5.45.00 Bqkg^{-1} for^{40} K with the sediments. The calculated average absorbed dose rate (32.75nGyh^{-1}) in air due to gamma ray from the studies on these sediments were found to be 23.83% less that the world measure average 43nGyh^{-1} [14]. Likewise the average hazard indexes (0.19 and 0.24) obtained for both external and internal exposure respectively do not exceeded the limits set by (ICRP, 2000) [7]. Therefore the lake's sediment does not pose much or any threat to the public, although study shows that radioactivity measured

in lakes is usually higher than that of flowing river waters, because a significant part of the radioactive substance brought in by other tributary rivers accumulates in it, [13]. But that of Kainji Lake has lower natural radioactivity and this observation could be associated to the continued replenishment of the lake's sediments due to constant elevated flow.

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