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Assessment of the Radiological Impacts of Radionuclides in Soil Samples of Flood Ravaged Areas in Isoko North and South LGA, Delta State, Nigeria

EGBE, D. O.[1,*], *AGBALAGBA, E. O.*[1]

[1]*Department of Physics, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria*

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ABSTRACT

This dissertation investigates the impact of natural radioactivity in soil samples collected from flood-affected areas in the Isoko North and South Local Government Areas (LGAs) of Delta State, Nigeria. The aim was to identify potential radiological health risks in these areas, where periodic flooding may affect the distribution of naturally occurring radioactive elements.
Gamma spectrometry detectors were used to examine soil samples from both flood-damaged and non-flooded control points in order to quantify the activity concentrations of radionuclides 238U, 232Th, and 40K. The analysis found that the average activity concentrations of 238U ranged from 25.67 Bqkg^{-1} in flood-prone areas to 8.13 ± 1.73 Bqkg^{-1} in control zones. The concentrations of 232Th and 40K also varied, with notable ranges in flood-exposed areas compared to control samples, highlighting an increase potentially linked to flood dynamics.
Radiological hazard indices, such as the Absorbed Dose Rate (ADR), Annual Effective Dose Equivalent (AEDE), and Excess Lifetime Cancer Risk (ELCR), were calculated. ADR values ranged from 14.58 nGyh^{-1} to 26.98 nGyh^{-1}, while AEDE values averaged 25.20 µSvy^{-1}, both well below UNSCEAR's recommended safety thresholds. The study reveals that flooding alters soil radionuclide distribution, with most areas remaining within safe radiation limits. However, elevated 238U levels in some flood-prone sites exceed WHO thresholds, highlighting the need for continued monitoring and assessment of potential risks. This research concludes by suggesting that Isoko North and Isoko South LGAs conduct periodic evaluations to track potential cumulative effects on public health and the environment, thereby providing crucial data to guide future environmental safety and public health efforts in flood-affected areas.

1. INTRODUCTION

Natural sources of radioactivity such as ^{238}U, ^{232}Th, and ^{40}K, is a major source of background radiation exposure globally, contributing to about 80% of total exposure (UNSCEAR, 1993). These radionuclides are present in very low concentrations in Earth's crust, and are redistributed through various processes, including natural phenomena like erosion and sedimentation, and human activities such as mining and oil exploration (Francis et al, 2015). The redistribution of these radioactive materials poses a potential health risk, and this concern has prompted researchers to conduct background checks and detect radionuclide concentrations, when predicting changes in radiation levels caused by nuclear accidents, industrial activities, natural disasters, and other human-induced events (NRC, 1999).

In the Niger Delta region (especially riverine areas), flood is an annual occurrence that affects communities and

*Corresponding author, e-mail: egbedominion@gmail.com
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the environment. This raises concerns about the redistribution of radionuclides in the environment, as floodwaters have the potential to cause soil erosion and transport radionuclides from one area to another, which can alter the concentration of naturally occurring radionuclides in soil, thus influencing radiological safety. Isoko North and South LGAs of Delta State, is an important area for investigating the impact of flooding on the concentration level of natural occurring radionuclides in soil. While the socioeconomic impact of flooding is constantly investigated and documented, the long-term impacts on environmental health and safety, including the potential changes in radioactivity concentration in soil, is largely unexplored. Therefore, it is imperative to investigate the radioactivity levels in the built-up areas of the environment and assess the radiological consequences.

Some radioactivity studies have been previously carried out in soil, sediment, and environmental samples in various parts of the world (Bashir et al., 2013; Agbalagba, 2016; Agbalagba and Esi, 2022; Eke et al., 2022; Orosun et al., 2022; Abayiga et al., 2022; Emumejaye et al., 2018; Ibrahim et al., 2014; Durusoy and Yildirim, 2017; Rilwani et al., 2010; Esi et al., 2019; Yang et al., 2022; Joel et al., 2021; Nurokhim et al., 2020). This study seeks to address this knowledge gap by evaluating the activity concentrations of ^{238}U, ^{232}Th, and ^{40K} in the soil samples that were collected from flood-affected areas and non-flooded areas in Isoko North and South LGAs, Delta State.

The objectives of the present study are to assess the natural radioactivity concentration in soil samples from flood-affected and non-flooded areas in Isoko North and South LGAs, Delta State. Activity concentrations of ^{238}U, ^{232}Th, and ^{40}K will be measured using sodium iodide (NaI) gamma spectrometry detectors. The results will be used to evaluate the concentration level across varying flood conditions and determine the potential health risks associated with exposure to natural radiation in flood-ravaged areas. Ultimately, this study will serve as a baseline for understanding the potential health risks associated with exposure to natural radioactivity in flood-prone areas and is expected to benefit stakeholders such as government agencies, environmental organizations, and residents of flood-affected areas.

2. MATERIALS AND METHODS

a. Area of Study

The study areas in Figure 1 cover selected communities in Isoko region a part of the Niger Delta region which is known for its elevated levels of natural radioactivity due to the geological composition of the area and the presence of mineral deposits. The Isoko region is a lowland area that is prone to flooding and its well-suited for this research as it has a long history of flooding, and the people of the region are well-aware of the challenges that flooding poses, including the flood disaster in 2012 and 2022.

The study encompasses nine distinct communities: Ozoro, Ellu, Ovrode, Ofagbe, Oleh, Irri, Idheze, Utie, and Orie. Soil samples were meticulously collected from each community at depths of 10-20 cm, representative of the upper soil layers most likely to be impacted by flooding. These samples were subsequently sent to the National Institute of Radiation Protection and Research under the National Nuclear Regulatory Authority (NNRA) at the University of Ibadan in Oyo state, using gamma spectrometry with sodium iodide (NaI) as detector.

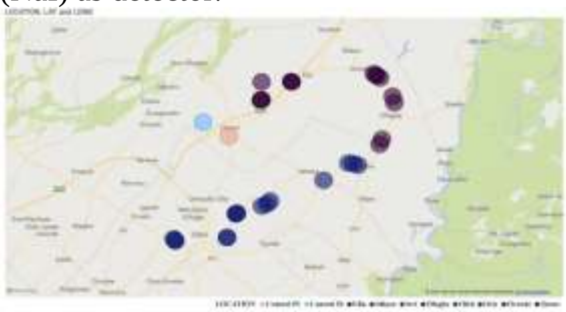

Figure 1: Map of the Area of Study

b. Radiological Hazard Indices

These indices take into account the various aspects of radiation exposure and can be used to estimate the radiological effect of samples contaminated by radionuclides such as ^{238}U, ^{232}Th, and ^{40}K.

a. Gamma Absorbed Dose rate (DR)

The absorbed dose rate (DR) at 1m above the ground (in $nGyh^{-1}$) was calculated using the equation (Avwiri et al., 2015);

$$DR\ (nGyh^{-1}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \quad (1)$$

where C_{Ra}, C_{Th}, and C_K are the concentrations of Radium, thorium and potassium respectively.

b. Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent received by a member of the public is calculated from the absorbed dose rate by applying dose conversion factor of 0.7 Sv/Gy and occupancy factor of 0.2 for outdoor. AEDE was determined using the equation(Agbalagba et al., 2013);

$$AEDE(\mu Svy^{-1}) = \text{Absorbed dose (DR) (nGy/h)} \times 8760\ h \times 0.7\ Sv/Gy \times 0.2 \times 10^{-3} \quad (2)$$

c. Excess Lifetime Cancer Risk (ELCR)

The Excess Lifetime cancer risk (ELCR) was calculated using the following equation (Jankowski et al., 2011);

$$ELCR = AEDE \times DL \times RF \quad (3)$$

Where AEDE is the Annual Equivalent Dose Equivalent, DL is the average duration of life (estimated to be 70 years), and RF is the Risk Factor (Sv^{-1}). For stochastic effects, ICRP uses RF as 0.05 for public.

d. Representative Gamma Index (I_{yr})

It is used to estimate the gamma radiation hazard associated with the natural radionuclides in the investigated samples. The representative gamma index is estimated as follows (NEA, 1979);

$$I_{yr} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (4)$$

where A_{Ra}, A_{Th} and A_K are the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil samples.

e. Internal and External radiation Hazard Index

The internal exposure to ^{222}Rn and its radioactive daughters can be controlled by the internal hazard index (Beretka and Matthew, 1985).

The internal hazard index was calculated using:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (5)$$

The external hazard index due to gamma radiation was evaluated using the relations (Ramasamy et al., 2009);

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (6)$$

where, A_{Ra}, A_{Th} and A_K are the radioactivity concentration in $Bqkg^{-1}$ of ^{226}Ra, ^{232}Th, and ^{40}K respectively. For the radiation hazard to be negligible or insignificant, the external hazard index must be in conformity with the criterion of $\boldsymbol{H_{ex} \leq 1}$.

3. RESULTS AND DISCUSSION

Table 1 shows that the average activity concentrations in Isoko North LGA ranged from 110.79 to 211.88 Bq/kg for ^{40}K, 20.75 to 25.67 Bq/kg for ^{238}U, and 3.74 to 9.95 Bq/kg for ^{232}Th. It was also observed that the control point for non-flooded area had the lowest concentration for ^{40}K (52.48 Bq/kg) and ^{238}U (13.37 Bq/kg) levels, however some of the sample location in Ozoro and Ofagbe had elevated activity concentration ^{238}U (51.01 Bq/kg and 53.26 Bq/kg, respectively), which surpasses world's permissible limits (UNSCEAR, 2000) for naturally occurring radionuclides. In Isoko South LGA, the average activity concentrations ranged from 99.79 to 219.01 Bq/kg for ^{40}K, 16.07 to 23.04 Bq/kg for ^{238}U, and 4.78 to 9.78 Bq/kg for ^{232}Th. Also, the non-flooded control point exhibited the highest average activity concentration for 40K (300.76 Bq/kg) and ^{232}Th (17.69 Bq/kg) concentrations, while some sample areas in Orie and Idheze, recorded high levels of ^{238}U which exceeded

Table 1: This table presents the specific activity concentrations of various radionuclides in soil samples collected from the study area.

S/N	LGA	SAMPLE LOCATION	LATITUDE	LONGITUDE	40K (Bq/kg)	238U (Bq/kg)	232Th (Bq/kg)
1.	ISOKO SOUTH	OLEH	5.4544396	6.186390876	110.92 ± 6.06	4.57 ± 0.81	BDL
2.		OLEH	5.45489120	6.186108589	251.25 ± 12.10	26.52 ± 2.02	13.52 ± 0.75
3.		OLEH	5.4561176	6.18521976	294.87 ± 16.11	32.47±6.12	5.91 ± 0.37
		AVERAGE			**219.01**	**21.19**	**6.48**
4.		IRRI	5.4570829	6.2243471	194.86 ± 10.71	7.00 ± 1.34	12.79 ± 0.80
5.		IRRI	5.4571027	6.224565	81.11 ±4.50	BDL	1.20 ± 0.08
6.		IRRI	5.475442288	6.230980083	185.05 ± 10.19	18.05 ± 3.44	2.89 ± 0.18
7.		IRRI	5.47568915	6.231012129	145.04 ± 7.95	32.47 ± 4.83	0.34 ± 0.02
8.		IRRI	5.47607558	6.23182556	123.94 ± 5.97	22.84 ± 1.75	6.67 ± 0.37
		AVERAGE			**146.00**	**16.07**	**4.78**
9.		IDHEZE	5.483205397	6.253718594	68.95 ± 3.84	BDL	15.03 ± 0.93
10.		IDHEZE	5.485604	6.256116	119.16±6.57	**45.77 ± 7.43**	9.83 ± 0.61
11.		IDHEZE	5.501721	6.295585	111.26±5.36	13.85 ± 1.10	4.49 ± 0.25
		AVERAGE			**99.79**	**19.87**	**9.78**
12.		ORIE	5.515096	6.313749	190.15 ± 10.29	11.87 ± 2.39	6.77 ± 0.42
13.		ORIE	5.514809	6.317307	274.48 ± 14.76	11.31 ± 2.45	2.77±0.18
14.		ORIE	5.513502	6.320726	144.26 ± 7.88	**45.96 ± 7.02**	16.49 ± 1.02
		AVERAGE			**202.96**	**23.04**	**8.67**
15.		CONTROL_IS	5.54706	6.206724	300.76 ± 16.49	8.13 ± 1.73	17.69 ± 1.09
16.	ISOKO NORTH	OFAGBE	5.529776	6.336775	203.49±11.32	**53.26 ± 7.92**	BDL
17.		OFAGBE	5.533789	6.338479	144.04±7.92	7.35 ± 1.55	4.02 ± 0.25
18.		OFAGBE	5.562292	6.347586	292.38±15.89	BDL	7.33 ± 0.46
19.		OFAGBE	5.567288	6.346319	78.70±4.34	22.38 ± 3.86	3.59 ± 0.22
		AVERAGE			**179.65**	**20.75**	**3.74**
20.		OVRODE	5.581624	6.336985	22.67±1.26	22.17 ± 3.47	4.94 ± 0.31
21.		OVRODE	5.583608	6.334417	379.99±20.28	**40.90 ± 6.23**	17.80± 1.09
22.		OVRODE	5.583581	6.334417	379.67±20.75	17.27 ± 3.12	4.85 ± 0.30
23.		OVRODE	5.58496	6.332378	65.20±3.64	3.96 ± 0.82	1.53 ± 0.10
		AVERAGE			**211.88**	**21.08**	**7.28**
24.		ELLU	5.5786356	6.272012	254.73±13.68	22.53 ± 3.91	3.44 ± 0.22
25.		ELLU	5.578578	6.271818	155.26±8.46	3.36 ± 0.63	3.24 ± 0.20
26.		ELLU	5.57885	6.271632	45.03±2.50	30.60 ± 5.54	1.20 ± 0.08
27.		ELLU	5.578548	6.249842	108.96±6.06	12.62 ± 2.24	8.49 ± 0.53
		AVERAGE			**141.00**	**21.08**	**7.28**
28.		OZORO	5.564537	6.249848	190.15±10.34	11.50 ± 2.36	16.00 ± 0.99
29.		OZORO	5.564403	6.249285	136.81±7.48	**51.01 ± 7.63**	10.70 ± 0.67
30.		OZORO	5.564607	6.249636	5.41±0.27	14.50. ± 1.81	3.16±0.18
		AVERAGE			**110.79**	**25.67**	**9.95**
31.		CONTROL_IN	5.536152	6.225840	52.48 ± 2.89	13.37 ± 2.36	10.29 ± 0.64

Table 2: This table presents the calculated radiometric parameters derived from the activity concentration data of radionuclides in soil samples which is essential for evaluating the radiological hazards posed to the local population and environment.

S/N	LGA	LOCATION	ADR ($nGyh^{-1}$)	AEDE (μSvy^{-1})	ELCR ($\times 10^3$)	$I_{\gamma r}$	H_{ex}	$Ra_{eq.}$ ($Bqkg^{-1}$)
1.	ISOKO NORTH	OFAGBE	19.333	23.706	0.083	0.295	0.108	39.922
2.		OVRODE	22.969	28.169	0.099	0.355	0.129	47.800
3.		ELLU	16.334	20.032	0.070	0.250	0.092	33.986
4.		OZORO	22.491	27.583	0.097	0.345	0.131	48.434
5.		CONTROL_IN	14.581	17.882	0.063	0.227	0.087	32.126
		Mean	**19.14**	**23.47**	**0.0824**	**0.2944**	**0.1094**	**40.4536**
6.	ISOKO SOUTH	OLEH	22.833	28.002	0.098	0.352	0.128	47.312
7.		IRRI	16.399	20.112	0.070	0.252	0.092	34.147

8.		IDHEZE	19.252	23.611	0.083	0.297	0.112	41.547
9.		ORIE	24.352	29.865	0.105	0.376	0.138	51.082
10.		CONTROL_IS	26.983	33.092	0.116	0.432	0.153	56.585
		Mean	**21.9638**	**26.9364**	**0.0944**	**0.3418**	**0.1246**	**46.1346**
		WORLD AVERAGE (UNSCEAR, 2000)	84	70	0.29	1	1	370

the world limits (45.96 Bq/kg and 45.77 Bq/kg, respectively). These findings suggest that flooding significantly increases the variability of radionuclides concentration which could be due to the movement and deposition of sediments in the flood-affected regions.

Table 2 shows that the Absorbed Dose Rate (ADR) ranged from 16.399 $nGyh^{-1}$ to 26.98 $nGyh^{-1}$ in Isoko South, with an average of 21.96 $nGyh^{-1}$, and from 14.59 $nGyh^{-1}$ to 22.97 $nGyh^{-1}$ in Isoko North, with an average of 19.14 $nGyh^{-1}$. These values are lower than the world average of 84 $nGyh^{-1}$ given by UNSCEAR (2000), and compares well with Eke et al. (2022) values of 16.70 to 52.10$nGyh^{-1}$.

The Annual Effective Dose Equivalent (AEDE) ranged from 17.88 µSv/y (control point) to 28.17 µSv/y (Ovrode) with a mean of 23.47 µSv/y in Isoko North LGA; while in Isoko South LGA, the AEDE ranged from 20.11 µSv/y (Irri) to 33.09 µSv/y (control point) with a mean of 26.94 µSv/y. These values are lower than the world standard of 70μSvy^{-1} and compare quite well with Emumejaye et al. (2018) with an average of 58.50μSvy^{-1}.

The Excess Lifetime Cancer Risk (ELCR) in soil samples collected from Isoko North LGA ranges from 0.063 ($\times 10^{-3}$) for the control point sample site to 0.099 ($\times 10^{-3}$) for Ovrode community, with mean value of 0.0824 $\times 10^{-3}$; while in Isoko South LGA the ELCR ranges from 0.070 ($\times 10^{-3}$) for Irri community to 0.116 ($\times 10^{-3}$) for the control point sample site , with mean value of 0.0944 $\times 10^{-3.}$ These values were below the limit as presented by UNSCEAR (2000) which indicates that the residents living around Isoko region are safe and will not likely develop cancerous growth due to constant flooding.

The Radium Equivalent activity (Ra_{eq}) in Isoko South LGA ranged from 34.147 $Bqkg^{-1}$ in Irri community to 56.585 $Bqkg^{-1}$ in the control point with a mean value of 46.1346 $Bqkg^{-1}$; and the Ra_{eq} value ranged from 32.126 in the control point to 48.434 in Ozoro with a mean value of 40.4536 in Isoko North LGA. These values compared quite well with Taiwo et al. (2014), Bashir et al. (2013) value of 187.2±7.8 $Bqkg^{-1}$ and are well below the permissible limit of 370 $Bqkg^{-1}$ given by (UNSCEAR, 2000). This reveals that, if the soil of the study area is used as components of building materials, it poses no radiological concern to occupants of such building.

The external hazard indices for Isoko South LGA ranged from 0.092 in Irri community to 0.153 in the control point with an average of 0.1246; and for Isoko North LGA, the H_{ex} ranged from 0.087 in the control point to 0.131 in Ozoro with an average of 0.1094 which is lower than unity.

4. CONCLUSION

The primary observation from this research is that flooding significantly influences the distribution of natural radionuclides in soil as the concentration of ^{40}K, ^{238}U, and ^{232}Th showed considerable variability across flood-affected sites, with some samples exceeding international safety limits for ^{238}U. This redistribution process can be as a result of erosion, and mixing of soils by floodwaters, which may alter the uniformity of radionuclides concentrations, and unlike non-flooded control points that showed relatively stable and consistent radionuclides concentrations, as these areas were not subjected to the disruptive effects of flooding.

Despite the variation in the radionuclides concentrations observed in flood-affected areas, the radiological assessments including the Gamma Dose Rate (ADR), Annual Effective Dose Equivalent (AEDE), Excess Lifetime Cancer Risk (ELCR), Radium Equivalent (Ra_{eq}), External Hazard Indices (H_{ex}), and Gamma Representative Index (I_{γ})—indicate that the radiation levels in all study sites, both flood-affected and control points, remain well within international safety standards.

However, there's the need for continuous environmental monitoring in areas prone to natural disasters (such as floods) and targeted mitigation strategies to address potential environmental and health risks due to the localized anomalies in ^{238}U concentrations. This study highlights the importance of sustained environmental monitoring in flood-prone regions to ensure public safety and address the long-term effects of radionuclide redistribution.

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