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Assessment of Terrestrial Gamma Radiation and Associated Radiogical Risks in Selected Oil-Spill Communities of the Niger Delta, Nigeria

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ABSTRACT
The assessment of the background ionizing radiation (BIR) levels and associated radiological health-risks in selected oil-spill communities of the Niger Delta has been carried out. *In-situ* gamma radiation measurements were obtained using a well calibrated radiation meter. The measured exposure rates were converted to absorbed dose rates and later used to compute annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR). Organ-specific radiation doses were also computed for the radiosensitive organs. The BIR results for Rivers and Bayelsa ranged from 0.012 to 0.017 mR h^{-1} and 0.012 to 0.018 mR h^{-1} respectively. The corresponding mean values are 0.015 mR h^{-1}, 0.014 mR h^{-1} and 0.014 mR h^{-1} for Rivers, Delta and Bayelsa States respectively. The absorbed dose rates vary from 104.40–147.90 nGy h^{-1} and 104.40–156.60 nGy h^{-1} in Rivers State and Bayelsa State, with mean values of 130.50 and 120.71 nGy h^{-1}, respectively. Thus, the mean was all higher than the worldwide reference average of 59 nGy h^{-1}. The mean values of AEDE in Bayelsa and Rivers were 0.1653 mSv y^{-1} and 0.1480 mSv y^{-1} respectively < 1.0 mSv y^{-1}.Excess lifetime cancer risk (ELCR) ranged from 0.448×10^{-3} to 0.635×10^{-3} and 0.448×10^{-3} to 0.672×10^{-3} for Rivers and Bayelsa States respectively. The highest ELCR value was recorded at Tebidaba and Eleme, while Bodo City, Nembe and Obololi recorded the lowest values. The obtained mean values are higher than the permissible limit of 0.29×10^{-3}. The radiation to the different body organs showed that the testes received the highest radiation dose, whereas the liver recorded the lowest. There was no control result so these values are not evident enough to conclude that the oil-spill was the cause of the elevated BIR and radiological indices. However, the study provided base line data of radiation pollution on the impacted communities.

Keywords: Assessment, Health risks, Oil Spill, Radiological indices, Terrestrial gamma radiation

INTRODUCTION

The Niger Delta is a major petroleum-producing region of Nigeria and has experienced persistent environmental degradation associated with oil exploration, production, transportation and spills. Human activities, particularly industrial operations associated with the oil and gas sector, may influence background ionizing radiation levels in surrounding communities. Activities such as gas flaring at oil-gathering centres, crude-oil spills, and the use and handling of radioactive materials in geological mapping, well logging and industrial radiography may contribute to variations in environmental radiation levels (Agbalagba, 2017). It therefore becomes necessary to evaluate the level of induced technologically enhanced naturally occurring radioactive material (TENORM) that may lead to radiological burden on the oil spilled area (Anekwe and Avwiri, 2016).

The terrestrial gamma radiation in our environment originates mainly from naturally occurring radionuclides such as potassium, uranium and thorium (^{40}K, ^{238}U and ^{232}Th), which are naturally present in the rocks, waters and soils (UNSCEAR, 2008). The radiation emitted from naturally occurring radionuclides and human-induced activities constitutes a major sources of external exposure, which may result in acute and chronic health effects, as well as potential genetic damage, on the living organism which are living in affected environments (Agbalagba & Onoja, 2011; Jibiri et al., 2007; Jwanbot et al., 2012; Meltem & Gurse, 2010; Nooreldin et., 2015; Ugbede et al., 2020.

Several studies have shown that the present radionuclides concentration within our environment are due to the advancement of human activities in oil and Gas activities and in others related activities

which might affect our daily comfort. Human waste management, disposal such as medical waste material, industrial waste materials, research waste materials and commercial waste materials has elevated radionuclides concentration within the environment in recent time either directly or indirectly. Living things within the immediate environment are continually and unavoidably exposed to differences doses of background ionizing radiation due to due their presence in the environment Ugbede et al. (2017).

Several international organizations, including UNSCEAR, ICRP, WHO, and IAEA, have developed guidelines and recommendations aimed at assessing radiation risks and promoting the protection of humans and the environment from ionizing radiation (UNSCEAR, 2000; WHO,2003; Agbalagba & Anekwe, 2022). Previous studies have reported terrestrial radiation and natural radionuclides in oil-producing environments. Arogunjo et al. (2004) assessed terrestrial gamma radiation at 32 locations in the Delta region and provided baseline information on radiation from ^{40}K, ^{238}U and ^{232}Th. Ademola and Atare (2010) investigated soils within and around crude-oil flow and gas-compression stations in the Niger Delta and reported relatively low radionuclide concentrations and radiological hazard indices. More specifically, Chad-Umoren and Ohwekevwo (2013) examined the influence of crude-oil spillage on the gamma-

radiation status of soil and water in Ogba/Egbema/Ndoni, while Ovuomarie-kevin et al. (2018) assessed gamma radiation and radiological health risks in selected oil-spill communities of Bayelsa State. These studies demonstrate the importance of radiation monitoring in oil-impacted environments.

Despite these investigations, further site-specific assessment is necessary because oil-spill locations differ in geology, environmental conditions, duration of contamination and petroleum-related activities. The present study therefore aimed at assessing terrestrial gamma radiation levels and estimating associated radiological exposure and health risk indices in selected oil-spill communities across Rivers, Bayelsa and Delta States, Nigeria. The results provided additional baseline information for environmental radiation monitoring, radiation protection and environmental management in the Niger Delta.

MATERIALS AND METHODS

Study Area

The study area in the Niger Delta region of southern Nigeria, covering parts of Rivers, Bayelsa and Delta States located within latitude 4.39 to 5.95° N and longitude 5.65 to 7.38°E. The region is characterized by extensive rivers, creeks, wetlands, mangrove vegetation and freshwater swamps and is one of Nigeria's major areas of petroleum exploration and production. Consequently, the region has experienced numerous oil-spill incidents associated with petroleum exploration, production and transportation activities. The selected locations comprise Rumuekpe, Bodo City, Ahoada West, Eleme, Gokana, Iloma and Minima in Rivers State; Adibawa North-East 1, Nembe, Ogboinbiri, Ikarama, Tebidaba, Peremabiri, Obololi and Imiringi in Bayelsa State; and Ndokwa East in Delta State.

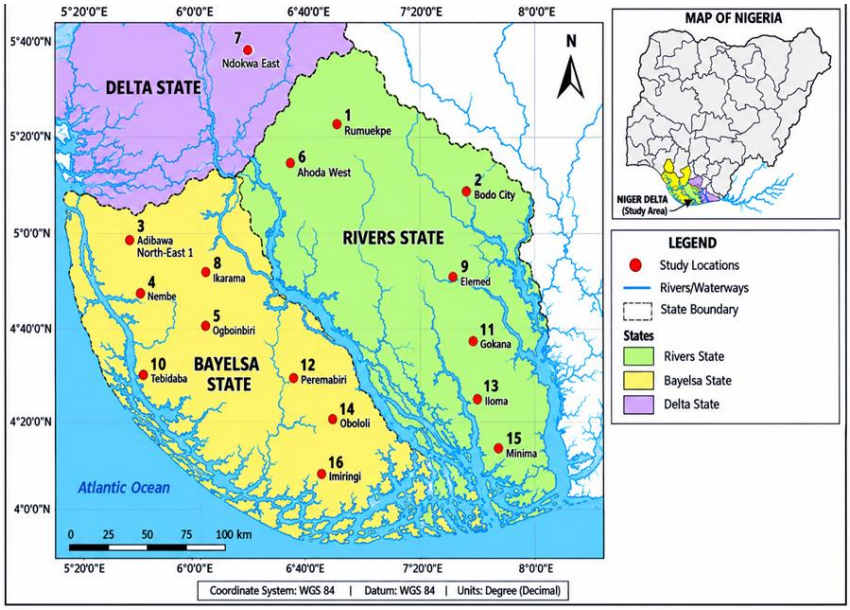


Figure 1: Map of Study Area

Materials

The materials used for the measurements are Radiation alert Monitor 200 and a global positioning system (GPS). The Radiation Alert Monitor 200 is a portable radiation survey instrument used for detecting and measuring ionizing radiation in the environment. It is capable of detecting alpha particles, beta particles, gamma rays, and X-rays, making it suitable for environmental radiation monitoring. The meter was calibrated with a 137Cs source of specific energy with accuracy of ±15% and it measures within temperature range of -10° to 50°C. The instrument operates on the Geiger–Müller (G–M) principle where the tube detects radiation, causes ionization (Ononugbo et al, 2016) and generate pulse. The pulse is electronically registered and displayed as a count in a chosen mode such as mR/hr. The GPS was reset upon getting to a new point and allowed to fully refresh before new reading was taken.

Measurements were done *in situ* to make sure the radionuclides were under their natural environmental characteristics. The radiation meter was held one meter (1m) above the ground level as reported by Laogun et al, 2006, during measurements which were done between 1100 and 1600 hours when radiation meters have maximum response to environmental radiation. A total of Sixteen (16) oil spill locations were surveyed. Three different readings were taken, each one after a beep, then the average value was recorded against corresponding GPS readings for each point probed.

Radiological Health Risk Parameters

The following radiation radiological health risk parameters are applied in estimating the health hazard due to human to exposure background ionizing radiation.

Absorbed Dose Rate

The absorbed dose rate in air was calculated to assess environmental radiation level of the study area using the equation below (Muhmoud et al, 2014)

Absorbed Dose = Exposure dose rate x 8.7 (nGy/hr) (1)

The Annual Effective Dose Equivalent (AEDE)

The annual effective dose equivalent for out radiation assessment was calculated using absorbed dose rate and dose conversion factor of 0.7 Sv/Gy with outdoor occupancy of 0.2 (UNSCEAR,2000). The annual effective dose equivalent (AEDE) is estimated using equation (2).

AEDE outdoor (mSv/yr) =

Dose rate (nGy/h)×8760h×0.7Sv/Gy×0.2 (2)

Excess Life Cancer Risk (ELCR)

The excess lifetime cancer risk was estimated to assess the probability of developing cancer in future due to exposure to radiation within the study area.

ELCR= AEDE× (DL)×RISK factor (RF) (3)

where DL is average duration of life (70 years) and RF is the fatal cancer risk factor, uses a fatal cancer risk factor value of 0.05 for public exposure (Taskin et al, 2009).

Effective Dose to Body Organs (Dorgan)

The effective dose to organs (Dorgan) was estimated to assess the radiation dose received by the various body organs and tissues due to inhalation and external exposure to radiation sources. The Dorgan of the body due to inhalation was calculated from the annual effective dose equivalent (AEDE) using Equation (5) as proposed by Darwish *et al*., (2015).

Dorgan (mSv/yr) =AEDE X F (4)

where F is the conversion factor of organ dose from air dose. The conversion factor (F) value for lungs, ovaries, bone marrow, testes, kidney, liver and whole body as given by ICRP (1996) are 0.64, 0.58, 0.69, 0.82, 0.62, 0.46, and 0.68, respectively.

RESULTS AND DISCUSSION

The results of *In-situ* measurement of gamma radiation exposure of the selected oil spill impacted communities are presented in Table 1 and the radiation dose to different body organ is presented in Table 2. Figures 2 to 5 show the comparison of background ionizing radiation exposure (BIR), absorbed Dose, Annual Effective Dose Equivalent (AEDE) and Excess life time cancer risk (ELCR) of Rivers State with standard value while Figure 6 to 9 show the comparison of background ionizing radiation exposure (BIR), absorbed Dose, Annual Effective Dose Equivalent (AEDE) and Excess life time cancer risk (ELCR) of Bayelsa State with standard. The comparison of radiation dose to different body organs of the study area is shown in Figure 10 and Figure 11 show the radiation percentage of the different body organs while Figure 12 show the Radiation contour map of the study area.

Table 1: Background Ionizing Radiation of the Selected Communities

State	Community/ Locations	Latitude (^{O}N)	Longitude (^{O}E)	Exposure Dose Rate (mR/hr)	Absorbed Dose Rate (nGy/hr)	AEDE (mSv/y)	ELCR 10^{-3}
Rivers	Rumuekpe	5.06300	6.76800	0.016	139.20	0.1707	0.598
	Bodo City	4.63150	7.27050	0.012	104.40	o.1280	0.448
	Ahoda West	5.09500	6.38500	0.016	139.20	0.1707	0.598
	Gokana	4.66850	7.37420	0.015	130.50	0.1600	0.560
	Eleme	4.78900	7.11200	0.017	147.90	0.1810	0.635
	Iloma	4.44200	7.16500	0.014	121.80	0.1494	0.523
	Minima	4.42000	7.19500	0.015	130.50	0.1600	0.560
	Mean			0.015	130.5	0.1653	0.560
Bayelsa	Adibawa Nort-East1	5.08000	6.32000	0.013	113.10	0.1387	0.486
	Tebidaba	4.57200	5.96200	0.018	156.60	0.1920	0.672
	Nembe	4.39300	6.42300	0.012	104.40	0.1280	0.448
	Ogboinbiri	4.58320	5.95410	0.013	113.10	0.1387	0.486
	Ikarama	5.14800	6.31200	0.016	139.20	0.1707	0.598
	Peremabiri	4.82100	6.10300	0.013	113.10	0.1387	0.486
	Obololi	4.82711	6.21131	0.012	104.40	0.1280	0.448
	Imiringi	4.82101	6.21132	0.014	121.80	0.1494	0.523
	Mean			0.014	120.713	0.1480	0.184
Delta	Ndokwa East	5.6505833	6.561611	0.014	121.80	0.1494	0.523
UNSCEAR	(2000)			0.013	59.0	1.0	0.29

Table 2: Radiation dose to different Body Organ of the selected Communities

State	Locations	Lungs	Ovaries	Bone Marrow	Testes	Kidney	Liver	Whole Body
RIVERS	Rumuekpe	0.109	0.099	0.118	0.140	0.106	0.079	0.116
	Bodo City	0.082	0.074	0.088	0.105	0.079	0.059	0.087
	Ahoda West	0.109	0.099	0.118	0.140	0.106	0.079	0.116
	Gokana	0.102	0.093	0.110	0.131	0.099	0.074	0.109
	Elemed	0.116	0.105	0.125	0.148	0.112	0.083	0.123
	Iloma	0.096	0.087	0.103	0.123	0.093	0.069	0.102
	Minima	0.123	0.111	0.132	0.157	0.119	0.088	0.131
	Mean	0.105	0.094	0.113	0.135	0.102	0.075	0.112
BAYELSA	Adibawa Nort-East1	0.089	0.080	0.096	0.114	0.086	0.064	0.094
	Tebidaba	0.123	0.111	0.132	0.157	0.119	0.088	0.131
	Nembe	0.082	0.074	0.088	0.105	0.079	0.059	0.087
	Ogboinbiri	0.089	0.080	0.096	0.114	0.086	0.064	0.094
	Ikarama	0.109	0.099	0.118	0.140	0.106	0.079	0.116

State	Locations	Lungs	Ovaries	Bone Marrow	Testes	Kidney	Liver	Whole Body
	Peremabiri	0.089	0.080	0.096	0.114	0.086	0.064	0.094
	Obololi	0.082	0.074	0.088	0.105	0.079	0.059	0.087
	Imiringi	0.096	0.087	0.103	0.123	0.093	0.069	0.102
	Mean	0.095	0.086	0.102	0.122	0.092	0.068	0.100
DELTA	Ndokwa East	0.096	0.087	0.103	0.123	0.093	0.069	0.102

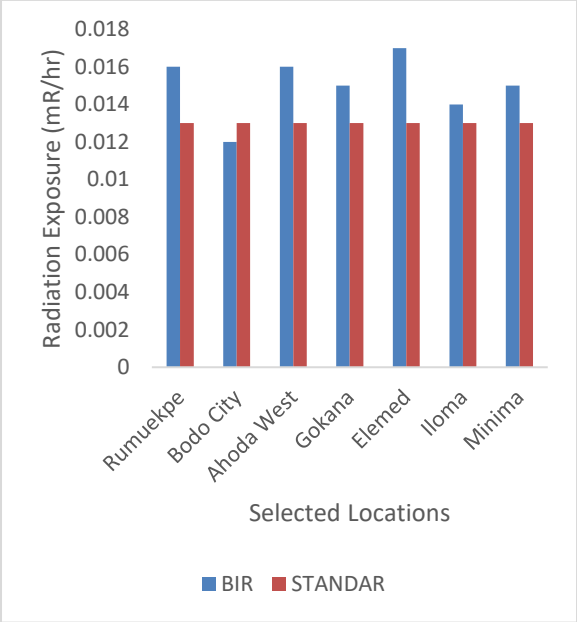


Figure 2: Comparison of Background ionizing radiation of Rivers State with Standard

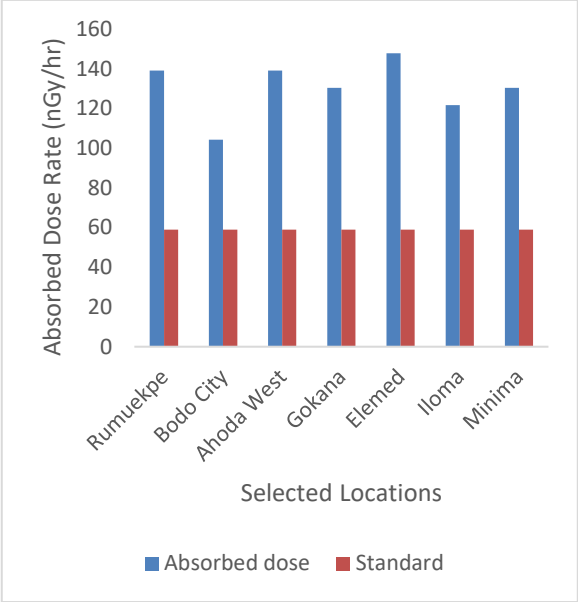


Figure 3: Comparison of Absorbed Dose rate of Rivers State with Standard

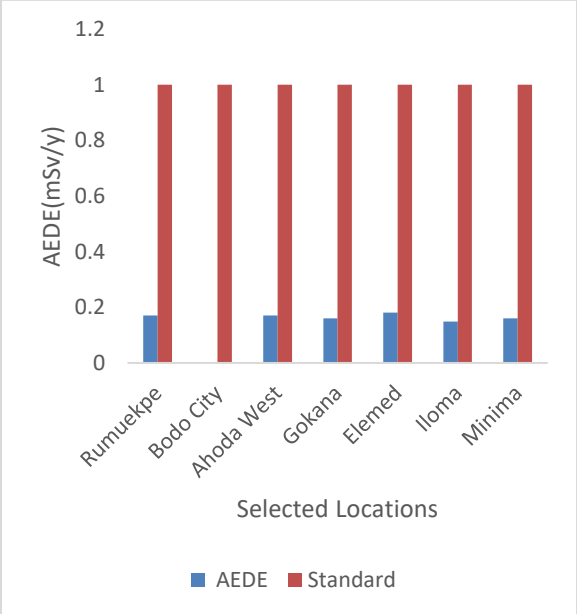


Figure 4: Comparison of AEDE of Rivers State with Standard

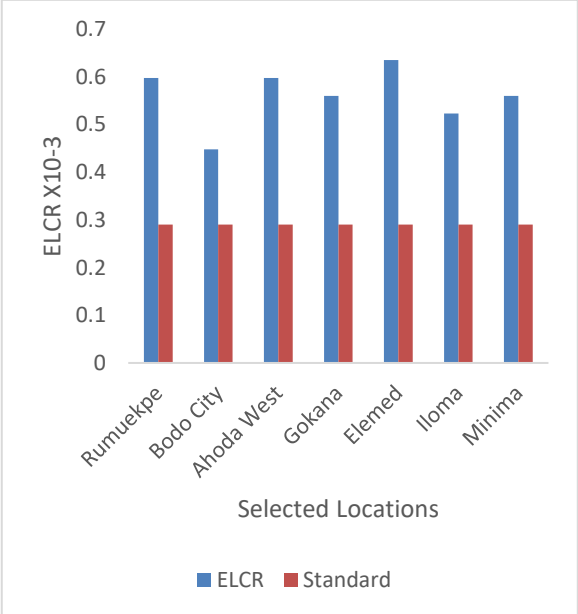


Figure 5: Comparison of ELCR of Rivers State with Standard

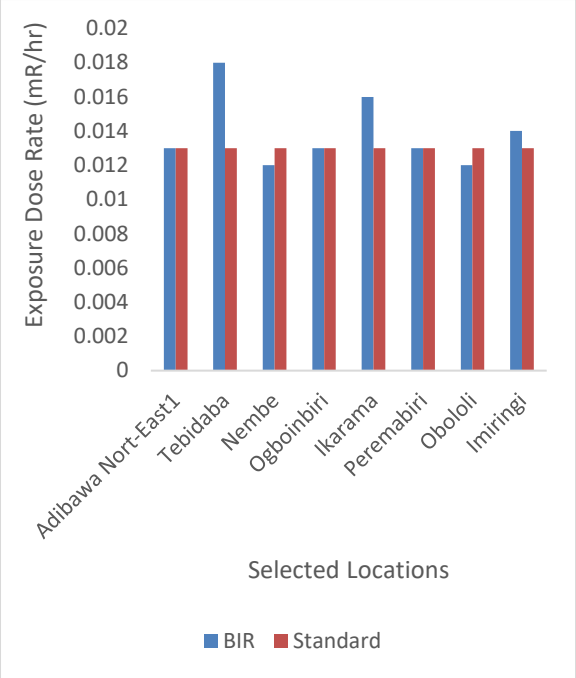


Figure 6: Comparison of Background ionizing radiation of Bayelsa with Standard

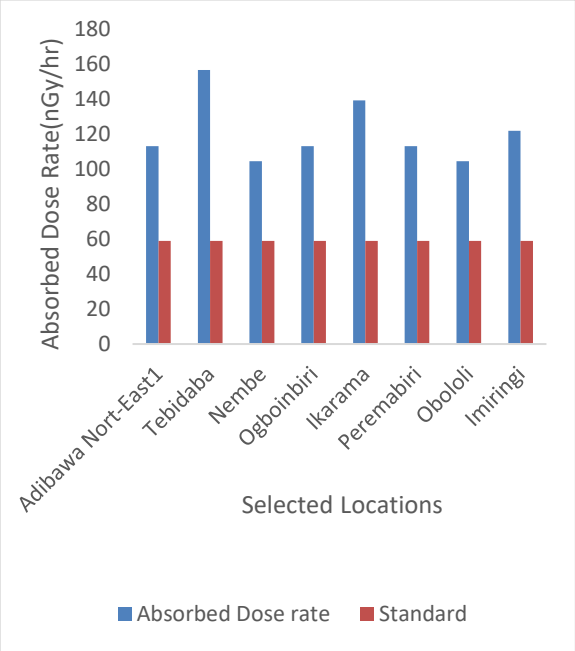


Figure 7: Comparison of Absorbed Dose Rate of Bayelsa with Standard

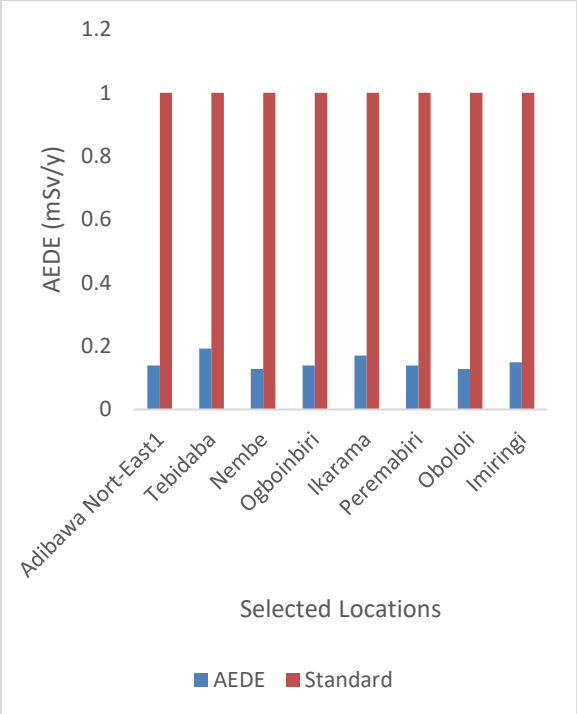


Figure 8: Comparison of AEDE of Bayelsa with Standard

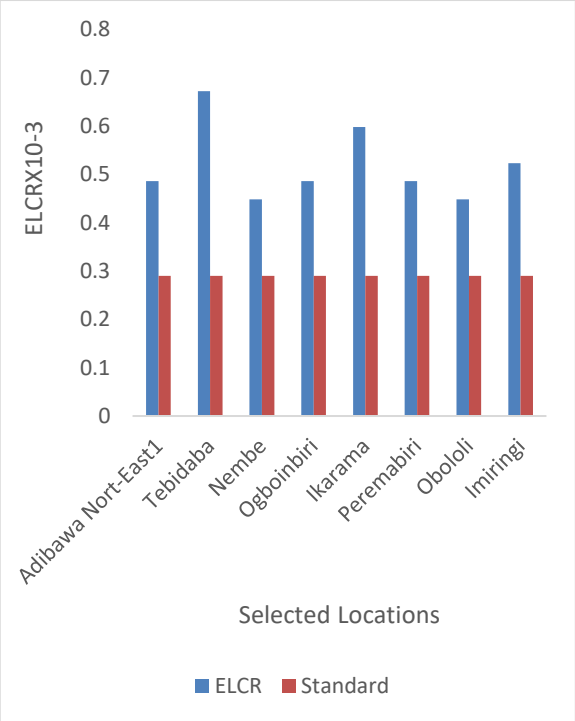


Figure 9: Comparison of ELCR of Bayelsa with Standard

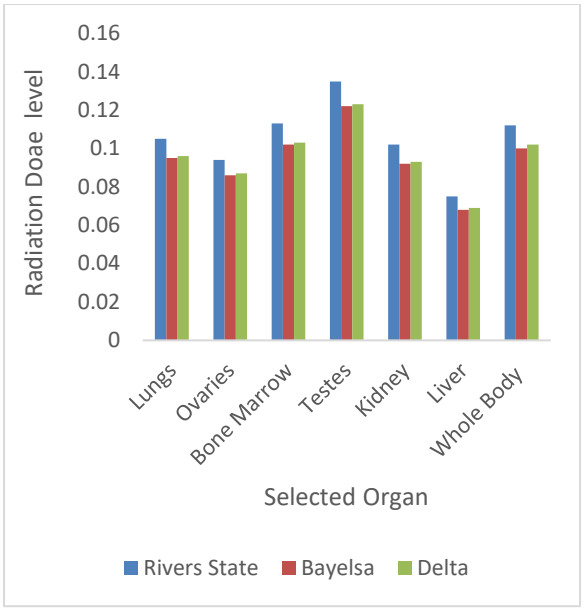


Figure 10: Comparison of Radiation Dose to different body Organ within the Locations

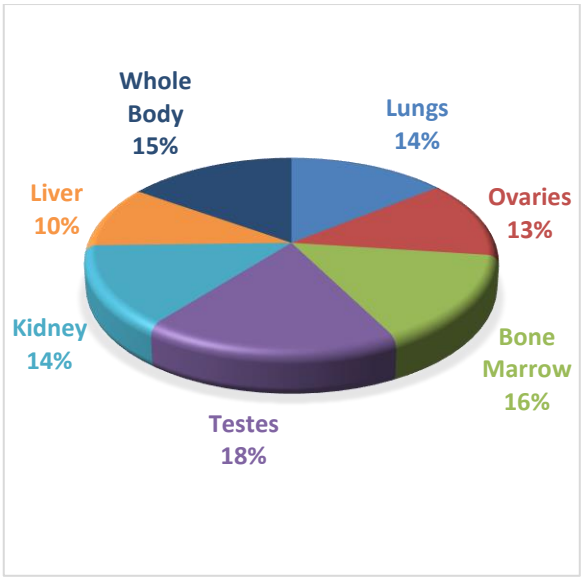


Figure 11: Percentage of Radiation Dose to different body Organ

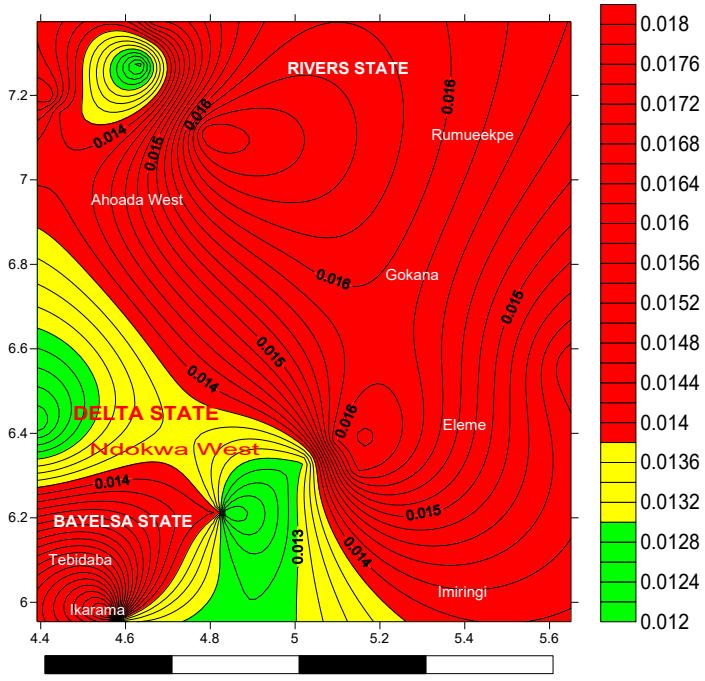


Figure 12: Radiation Contour Map of the study Area

Discussion

The results of the background ionizing radiation (BIR) levels of the selected oil spill impacted communities ranged from 0.012 to 0.017 mR h^{-1} and 0.012 to 0.018 mR h^{-1} for Rivers State and Bayelsa State respectively. The corresponding mean values are 0.015 mR h^{-1}. 0.014 mR h^{-1} and 0.014 mR h^{-1} for Rivers State, Delta State and Bayelsa State. These results indicate spatial variability in environmental radiation within the oil spill communities. The highest background ionizing radiation was recorded in Eleme, while the lowest value was recorded at Bodo City of Rivers State. Bayelsa State recorded, its highest value and lowest value at Tebidaba, and Obololi respectively.

The results, show that the obtained mean of BIR is higher than the recommended standard limit of 0.013 mR h^{-1} as stipulated by UNSCEAR 2024 and lower than the reported work of Anekwe and Nwii 2022. The high radiation level within the oil spill communities may be attributed to the combination of environmental, geological and anthropogenic factors and the spatial distribution of naturally occurring radioactive materials (NORM) in soil content. The absorbed dose rates vary from 104.40–147.90 nGy h^{-1} and 104.40–156.60 nGy h^{-1} in in Rivers State and Bayelsa State, with mean values of 130.50 and 120.71 nGy h^{-1}, respectively. Thus, the mean was all higher than the worldwide reference average of 59 nGy h^{-1} and within the reported ranged of Ugbede et al., (2020).

The estimated annual effective dose equivalents (AEDE) ranged from 0.1280 to 0.1810 mSv y^{-1} and 0.1280 to 0.1920 mSv y^{-1} with corresponding mean values of 0.1653 mSv y^{-1}, 0.1480 and 0.494 for Rivers State, Bayelsa State and Delta State Respectively. The obtained mean value is below the stipulated safe limit of 1.0 mSv y^{-1} as recommended by

UNSCEAR, (2000) and within the range reported by Avwiri, et al,. (2022). Highest value of AEDE was obtained at Tebidaba (0.1920 mSv y^{-1}), followed by Eleme (0.1810 mSv y^{-1}), while Bodo City, Nembe and Obololi recorded the lower values of 0.1280 mSv y^{-1}. The variation in the measured BIR and absorbed dose rates, confirming that the calculated annual dose is principally controlled by the ambient radiation within the study area. The result of the estimated excess lifetime cancer risk (ELCR) varied ranged from 0.448×10^{-3} to 0.635×10^{-3} and 0.448×10^{-3} to $0.672 \times 10^{-3}$for Rivers State and Bayelsa respectively. The highest individual estimate is recorded at Tebidaba (0.672×10^{-3}), followed by Eleme (0.635×10^{-3}), while Bodo City, Nembe and Obololi recorded the lowest values of 0.448×10^{-3}. The obtained mean values are higher than the recommended safe limit of 0.29×10^{-3}.
The calculated radiation doses to the different body organs show that testes has the highest radiation dose with eighteen percentages (18%) and liver has the lowest radiation dose of with ten percentages (10%) as shown in Figure 10. The radiation dose to the different body organ are all below the permissible limit of 1.0 mSy^{-1}. The obtained result for radiation dose to different body organ agreed with the work of Nwii et al., (2025). The radiation contour map presented in Figure 11 shows that radiation levels vary within the study area and the radiation distribution are not homogeneous across the selected oil spill communities. The areas around Eleme and Tebidaba exhibited comparatively higher background radiation, whereas Bodo City, Nembe, and Obololi recorded lower radiation values.

Conclusion

The assessment of the background radiation levels and associated radiological risks of some selected oil spill impacted communities in Rivers, Bayelsa and Delta States, Nigeria was carried out. The results showed spatial variations of background ionizing radiation (BIR), absorbed dose rate, annual effective dose equivalent (AEDE), and the excess lifetime cancer risk (ELCR). The variation in BIR is also evident in the contour map. Generally, these elevated indices are not at alert levels hence continues monitoring is strongly recommended.

Acknowledgement

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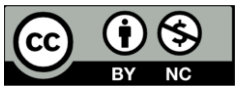
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