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Natural Background Ionizing Radiation In Ogoniland: A Post-Oil Spill Radiological Risk Evaluation Of Terrestrial Gamma Exposure And Stochastic Health Effects

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Abstract The study examines Natural background ionizing radiation in Ogoniland: A post-oil spill radiological risk evaluation of terrestrial gamma exposure and stochastic health effects**.** Calibrated dose rate surveys were performed in twenty communities across Tai and Khana Local Government Areas (LGAs) of Ogoniland to establish the first high resolution baseline of background ionizing radiation (BIR) and associated health indices after six decades of crude-oil perturbation. Mean outdoor exposure rates were 0.0046 ± 0.0007mR h^{-1} (Tai) and 0.0049 ± 0.001mRh^{-1} (Khana), translating to absorbed dose rates of 40.02 ± 6nGyh^{-1} and 42.63 ± 9nGyh^{-1} both 52 % below the 89nGyh^{-1} UNSCEAR world average. Annual effective dose equivalents averaged 0.061 ± 0.01 mSv (Tai) and 0.065 ± 0.01 mSv (Khana), less than 7% of the 1.0mSv global outdoor norm. Excess lifetime cancer risk (ELCR) estimates of (0.215 – 0.229) × 10^{-3} lie 21% under the 0.29 × 10^{-3} international benchmark, while organ specific effective doses to testes (0.043mSvy^{-1}) and ovaries (0.030mSvy^{-1}) remain less than 4% of the 1mSvy^{-1} tissue tolerance limit. Contour maps reveal a homogeneous low rate background ionizing radiation, confirming negligible radiological hazard for residents. The dataset serves as a reference for future TENORM monitoring and regional radiological protection policy.

Keywords: Exposure Rate, Absorbed dose, Excess Life Cancer Risk, Background Ionizing Radiation, Rados-31

1 Introduction

Naturally Occurring Radioactive Materials (NORM) are ubiquitous in the environment and are primarily derived from primordial radionuclides such as uranium-238 (^{238}U), thorium-232 (^{232}Th), and potassium-40 (^{40}K) [2,3] These radionuclides are found at different levels in soil, water, rocks, and air and they add considerably to the background ionizing radiation (BIR) levels in the one environment or the other. Although natural maturation of background radiation is believed to be harmless at that level, anthropogenic operations, including oil and gas exploration, mining, and waste discharge of industries, may increase the concentration of these radionuclides, resulting in Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) [38,1}.

Niger Delta and more so the Ogoniland situated in the Rivers State of Nigeria has been a centerpiece of exploration and drilling of crude oil since the late 1950s. Oil spills, gas flaring, and unlawful artisanal refining have been some of the practices that have led to large-scale environmental degradation in this region [30]. The fact that the environment is being subjected to such perturbations continuously is a concern to the possibility of the eventual radiological health effects of the local communities that may occur as a result of radiological health effects of radionuclides accumulating in the soil and water. The oil industry is not in active operation in Ogoniland anymore, but oil spills and other environmental nuisances still take place with disturbingly great frequency, which worsen the threat of radiological contamination [13].

Directly exposed to these environmental stressors are the Ogoni people who are fishermen and mostly farmers. The possible rise of the BIR levels with the accumulation of TENORM leads to a complete radiological evaluation to see the level of exposure and the health consequences. The primary objectives of the study are to assess background levels of ionizing radiations and related health risks in some of the Ogoni communities, with a perspective of establishing baseline information on the regulatory measures and health interventions to the communities.

2.1 Background Ionizing Radiation (BIR)

The three principal sources of background ionizing radiations are the terrestrial (primordial radionuclides), cosmic (cosmogenic radionuclides) and anthropogenic (man-made) sources [17]. The natural background radiation per capita of effective dose is estimated to be 2.4 mSv/y all over the world, with regional differences based on geological and geographical conditions [38]. In

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Nigeria, it has been documented that the level of BIR is high in the oil-producing areas. An example of such instances is the Rivers State, where the exposure has been found to surpass the global average of 100,000 mR/h, and in some areas effective doses of over 1.0 mSv/h were reported [34].

BIR levels were determined in crude oil-polluted soils of the communities of Baralue and Korokoro on Ogoniland in a recent study by [13]. The study established that in-situ and laboratories revealed that the annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) was increased in oil-spill-infested regions relative to control sites. The research took place in the view that, though the values were lesser than the global allowable levels, it was concluded that the occurrence of the spills of crude oil could have distorted the natural distribution of the radionuclides, and as such influenced the radiological health risk in the impacted communities.

3. Materials and Methods

3.1 Study Area and Sampling Design

The research took place in the Ogoniland, Rivers State, Nigeria, which is in four Local Government Areas (LGAs) Tai, Khana, Gokana, and Eleme. Forty communities were chosen and 10 communities each in LGA. Radiosurvey measurements were also conducted in-situ at 1 m above ground of Rados-31 and Polimaster PM1703GNA survey meter. Each sampling point was measured by GPS coordinates.

An on-site gamma-ray survey was conducted to preserve the in-situ physicochemical integrity of the sampling locations[17]. A hand-held, calibrated RDS-31 scintillation monitor served as the primary dosimeter; its response was verified against a Cs-137 reference source at the Environmental Radiation Laboratory, University of Ibadan, Nigeria prior to field deployment. Georeferencing was performed with a Garmin GPS-72H receiver (accuracy ± 3 m) to record decimal-degree coordinates for each point. The instrument window was set to display ambient equivalent dose-rate (µSv h^{-1}) and gross count-rate (counts min^{-1}); all readings were acquired between 13:00 and 16:00 LST, coinciding with the local atmospheric stability window that minimises cosmic-ray variability [34,7]

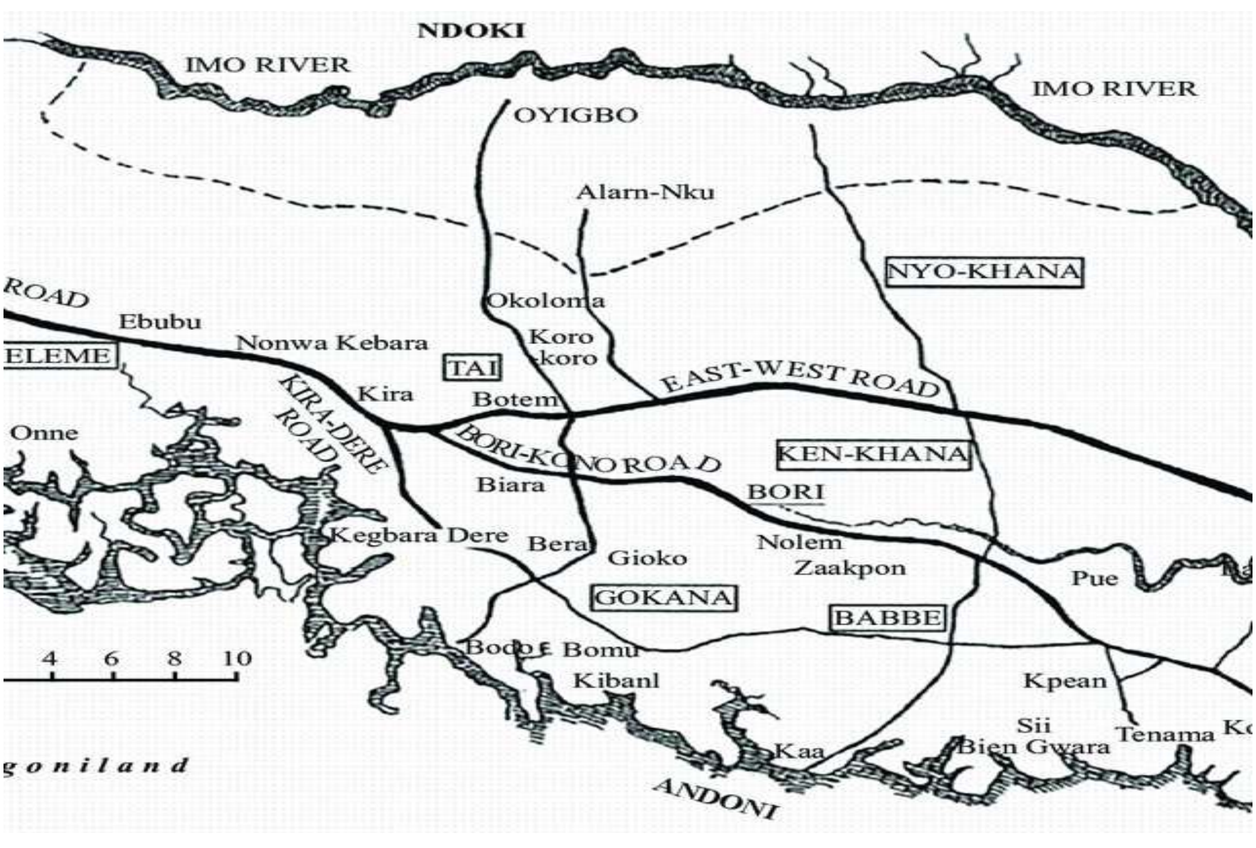

Fig. 1: Map of the Study Area of Ogoni

3 2 Radiological Risk Parameters

3.2.1 Absorbed Dose Rate

The absorbed dose rate quantifies the kinetic energy imparted to human tissue per unit mass per unit time by ionising radiation. Field exposure-rate readings ($\mu R\ h^{-1}$) were transformed to air-kerma rate ($nGy\ h^{-1}$) with the internationally accepted conversion [45]:

$$1\ \mu R\ h^{-1} = 8.7\ nGy\ h^{-1} = 76.2\ \mu Gy\ y^{-1}. \quad (1)$$

3.2.2 Equivalent Dose Rate

To account for the varying biological effectiveness of different radiation types, the exposure rate ($mR\ h^{-1}$) was further converted to whole-body equivalent dose rate using the National Council on Radiation Protection & Measurements [28] coefficient:

$$1\ mR\ h^{-1} = 8.77\ mSv\ y^{-1}. \quad (2)$$

3.3 Annual Effective Dose Equivalent (AEDE)

The annual effective dose received by an adult member of the public was estimated by folding the absorbed dose rate with the outdoor dose-coefficient ($0.7\ Sv\ Gy^{-1}$) and a conservative occupancy factor of 0.25 ($6\ h\ d^{-1}$ outdoors, $18\ h\ d^{-1}$ indoors)[43]:

$$AEDE\_outdoor\ (mSv\ y^{-1}) = D\ (nGy\ h^{-1}) \times 8760\ h \times 0.7\ (Sv\ Gy^{-1}) \times 0.25 \times 10^{-3}. \quad (3)$$

3.4 Excess Lifetime Cancer Risk (ELCR)

Following the Linear No-Threshold (LNT) model endorsed by ICRP (2021) and BEIR-VII (NRC, 2022), the probability of radiogenic cancer over a 70-year lifetime was calculated as:

$$ELCR = AEDE\_total\ (mSv\ y^{-1}) \times 70\ y \times 5.5 \times 10^{-2}\ Sv^{-1}. \quad (4)$$

The adopted risk coefficient ($5.5 \times 10^{-2}\ Sv^{-1}$) corresponds to the ICRP-103 nominal fatal-cancer risk factor for whole-population exposure to low-dose, low-dose-rate gamma radiation.

The probability that workers and resident adults will develop a radiation-induced malignancy over a lifetime was quantified with Equation (4), adopting the ICRP-60 stochastic model [19,32]:

$$ELCR = AEDE\ (mSv\ y^{-1}) \times 70\ y \times 0.05\ Sv^{-1} \quad (5)$$

Here, 70 y denotes the average life expectancy used for public-risk assessment and $0.05\ Sv^{-1}$ is the ICRP-60 nominal fatal-cancer risk coefficient for low-dose, low-dose-rate gamma exposure.

3.5 Organ-Specific Effective Dose Rate

To apportion the effective dose among radiosensitive tissues, organ dose rates were computed with Equation (5) [47]:

$$D_{organ}\ (mSv\ y^{-1}) = AEDE \times 0.8 \times F \quad (6)$$

The indoor occupancy factor is fixed at 0.8, while F ($Sv\ Gy^{-1}$) represents the ingestion dose-conversion factor for each organ: lungs 0.64, ovaries 0.58, bone marrow 0.69, testes 0.82, kidneys 0.62, liver 0.46 and whole body 0.68 [48, 38].

4.0 Results and Discussion

Radiological findings for the studied settlements are summarised in Tables 1–3, while the spatial variation of exposure rate, absorbed dose rate and excess lifetime cancer risk is displayed in Figures 2–7. Figure 8 illustrates the calculated effective organ dose (Dorgan, $mSv\ y^{-1}$) delivered to individual tissues of residents living within the oil- and gas-producing belt of Ogoni in Rivers State, Nigeria. Contour maps depicting the distribution of gamma radiation across Tai and Khana LGAs are provided in Figures 9 and 10, respectively

Table 1: The mean radiation exposure rate and estimated radiation risk parameters in Tai Local Government Area

Location	Geographical Position		Av. Bgrd. (mR/hr)	ADR ($nGyh^{-1}$)	AEDE ($mSvy^{-1}$)	ELCR x 10
T1 Ogu	04^0 44′6.99N	07012′48.78E	0.01	87	0.133	0.46
T2 Ekpor	$04^0$44′11.14N	$07^0$13′34.87E	0.003	26.1	0.0400113	0.1400395
T3 Kporghor	**04^{0}43′37.12N**	**07^{0}14′22,19E**	0.003	26.1	0.040	0.14
T4 Ogu Bolo	$04^0$44′23,62N	$07^0$13′21.53E	0.004	34.8	0.053	0.18
T5 Nonwa tal	**04^{0}44′36.68N**	**07**^{0}13′30.02E	0.006	52.2	0.080	0.28
T6 Gbam	**04**^{0}44′8,75N	**07**^{0}13′42.15E	0.005	43.5	0.067	0.23
T7 Goi	**04**^{0}41′11.57N	**07**^{0}14′20.98E	0.004	34.8	0.053	0.18
T8 Kira	**04**^{0}43′7.85N	**07**^{0}16′28.28E	0.004	34.8	0.053	0.18
T9 Bonte	$04^0$43′9.22N	$07^0$16′28.41E	0.004	34.8	0.053	0.18
T10 Borrobara	**04**^{0}44′10.45N	**07**^{0}14′40.39E	0.003	26.1	0.040	0.14
			0.0046	40.02	0.0612	0.215

Table 2: The mean radiation exposure rate and estimated radiation risk parameters in Khana Local Government Area

Location	Geographical Position	Av. Bgrd. (mR/hr)	Av. Bgrd. (μSv/hr)	Av. Bgrd. (mR/hr)	ADR nGyh-1	AEDE mSvy-1)	ELCR X 10^{-3}
K1 Bori	**04**^{0}39′56.01N	**07**^{0}22′34.09E	0.03	0.003	26.1	0.040	0.140
K2 Zaakpon	**04**^{0}37′00.84N	**07**^{0}24′7.72E	0.05	0.005	43.5	0.067	0.2333
K3 Kapnor	**04**^{0}37′25.49N	**07**^{0}23′26.39E	0.07	0.007	60.9	0.093	0.327
K4 Eeken	**04**^{0}37′27.83N	**07**^{0}23′22.73E	0.05	0.005	43.5	0.067	0.233
K5 Kaa	**04034′36.93N**	**07**^{0}22′0.05E	0.05	0.005	43.5	0.067	0.233
K6Kaa Water	**04**^{0}34′8.05N	**07**^{0}22′8.18E	0.05	0.005	43.5	0.067	0.233
K7 Gwara	**04**^{0}37′0.84N	**07**^{0}24′7.72E	0.04	0.004	34.8	0.053	0.187
K8 Betem	**04**^{0}38′37.33N	**07**^{0}24′44.21E	0.04	0.004	34.8	0.053	0.187

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K9 Wiyakara	**04**^{0}39′50.89N	**07**^{0}24′47.86E	0.04	0.004	34.8	0.053	0.187
K10 Bori 2	**04**^{0}40′42.94N	**07**^{0}21′21.15E	0.07	0.007	60.9	0.093	0.327
			0.049	0.0049	42.63	0.065	0.229

Table 3: Effective dose rate to different organs / tissues

S/no	Location Communities	AEDE (mSvy-1)	Lungs	Ovaries	Bone Marrow	Tastes	Kidney	Liver	Whole Body
1	K1 Bori	0.040	0.020	0.019	0.022	0.026	0.020	0.015	0.022
2	K2 Zaakpon	0.067	0.034	0.031	0.037	0.044	0.033	0.025	0.036
3	K3 Kapnor	0.093	0.048	0.043	0.052	0.061	0.046	0.034	0.051
4	K4 Eeken	0.067	0.034	0.031	0.037	0.044	0.033	0.025	0.036
5	K5 Kaa	0.067	0.034	0.031	0.037	0.044	0.033	0.025	0.036
6	K6Kaa Water	0.067	0.034	0.031	0.037	0.044	0.033	0.025	0.036
7	K7 Gwara	0.053	0.027	0.025	0.029	0.035	0.026	0.020	0.029
8	K8 Betem	0.053	0.027	0.025	0.029	0.035	0.026	0.020	0.029
9	K9 Wiyakara	0.053	0.027	0.025	0.029	0.035	0.026	0.020	0.029
10	K10 Bori 2	0.093	0.048	0.043	0.052	0.061	0.046	0.034	0.051
		0.065±0.005	0.033±0.003	0.030±0.002	0.0361±0.003	0.043±0.004	0.032±0.003	0.04±0.002	0.036 ± 0.003

AEDE = Annual Effective Dose Equivalent

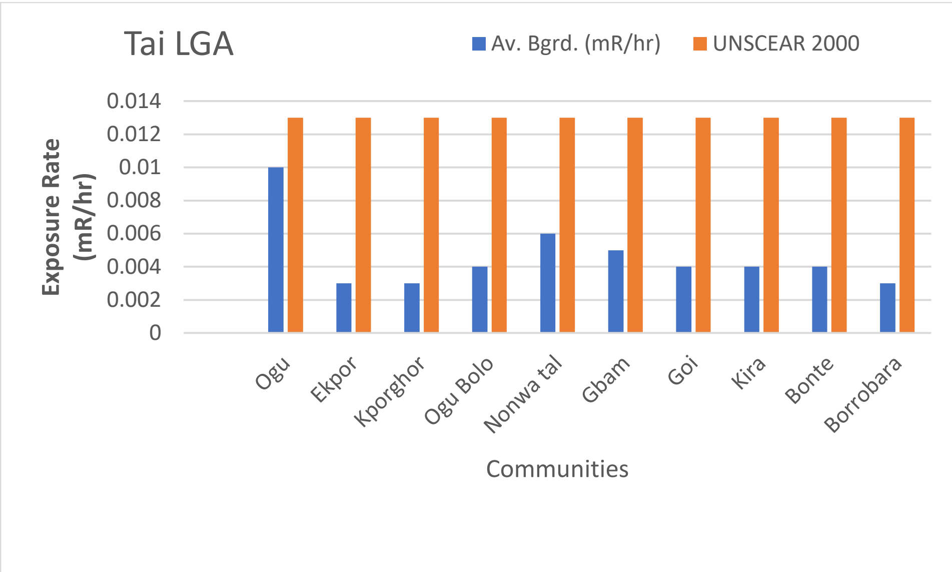

Figure 2: Comparison of measured BIR levels of Tai LGA with ICRP Standard

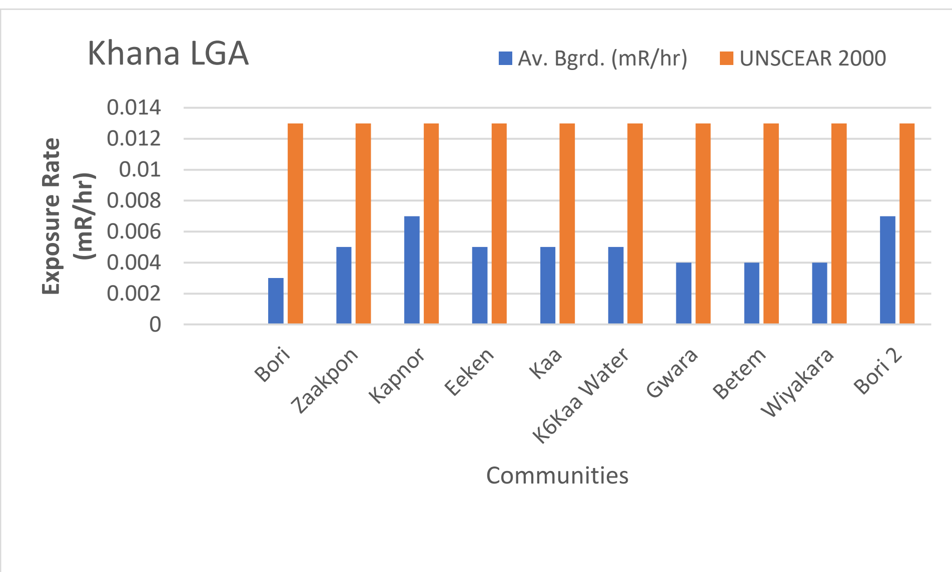

Figure 3: Comparison of measured BIR levels Khana of LGA with ICRP Standard

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The range of exposure rate from the ten communities in Khana local government area studied (0.003 to 0.007) mRh^{-1}). the overall mean exposure rate value of 0.005 mRh^{-1} from these communities, is lower when compared with the average dose rate value of 0.0065 mR/h to the population of Caspian coastal provinces in North of Iran obtained by [9], it agreed with [46] report on Khana exposure rates ranging from 0.003 to 0.007 mRh^{-1}, with a mean of 0.005 mRh^{-1}. and also lower than the ICRP standard of 0.013 mR/h (ICRP, 2003), 0.019mR/h [11] and the mean BIR values of 0.0156 mR/h from coastal communities in Burutu L.G.A, of Delta State, Nigeria [6] with similar geological ecosystem. This shows that the overall background ionizing radiation levels of the studied communities in the oil-producing area of Ogoni Rivers State are not raised. The mean absorbed dose rate values are 40.02 $nGyh^{-1}$ and 42.63$nGyh^{-1}$ for Tai and Khana LGAs, respectively. The overall mean value obtained in Tai and Khana LGA are lower than the permissible world value of 89 nGyh-1, The dose rates in Tai and Khana are significantly lower than both national and international averages, including regions within Nigeria. Ndokwa East and Cross River report higher values 59.0 and 64.52 nGy h^{-1} respectively [25] yet still remain below the 89 nGy h^{-1} threshold while the overall mean values in both LGAs are higher than the maximum and minimum values in Abomoosa and Minab in Hormozgan province south-east of Iran [14] and mean value of 69.63 nGy/h in oil fields and wells environments in Romania [15]

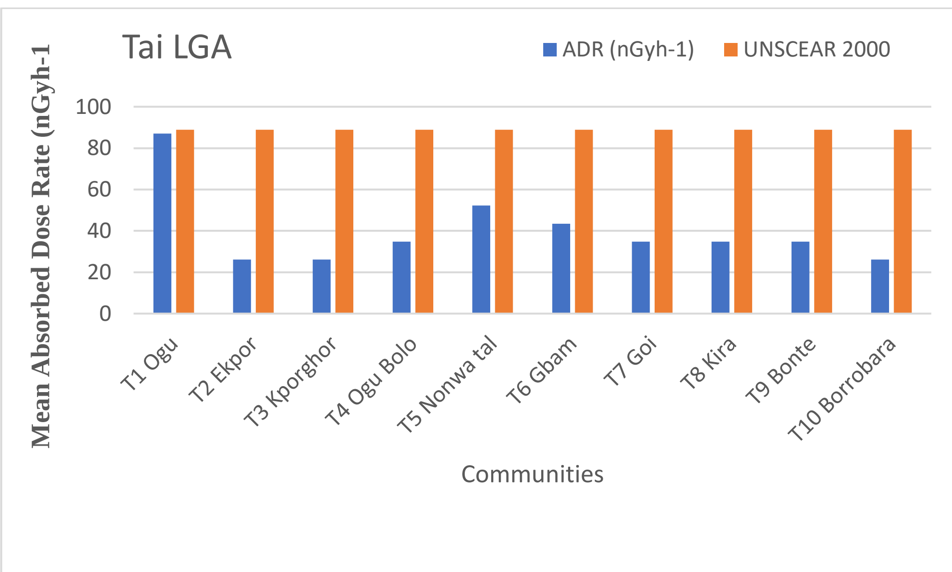

Figure 4 **Comparison of Average Absorbed Dose Rates in Tai LGA with UNSCEAR Standard**

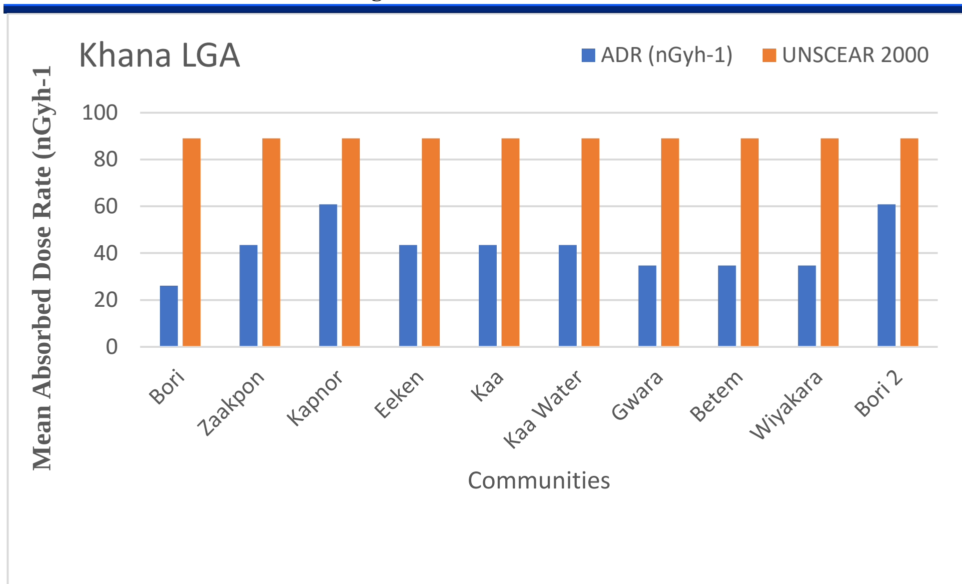

Figure 5: **Comparison of Average Absorbed Dose Rates in Khana LGA with UNSCEAR Standard**

The computed annual effective dose equivalents of 0.061 mSv y^{-1} (Tai LGA) and 0.065 mSv y^{-1} (Khana LGA) align with the 0.06–0.07 mSv y^{-1} recently reported for communities in oil-producing parts of Rivers State, Nigeria [16] and are only one-third of the 0.19 mSv y^{-1} measured in the crude-oil-impacted areas of Ogoniland [4]. Conversely, they are markedly below the 0.21–0.83 mSv y^{-1} range found in the high-background-radiation districts of Ramsar, Iran [26] and are an order of magnitude lower than the 1.0 mSv y^{-1} global average for outdoor terrestrial gamma exposure [24]. The consistently low values point to a negligible radiological burden at the surveyed locations.

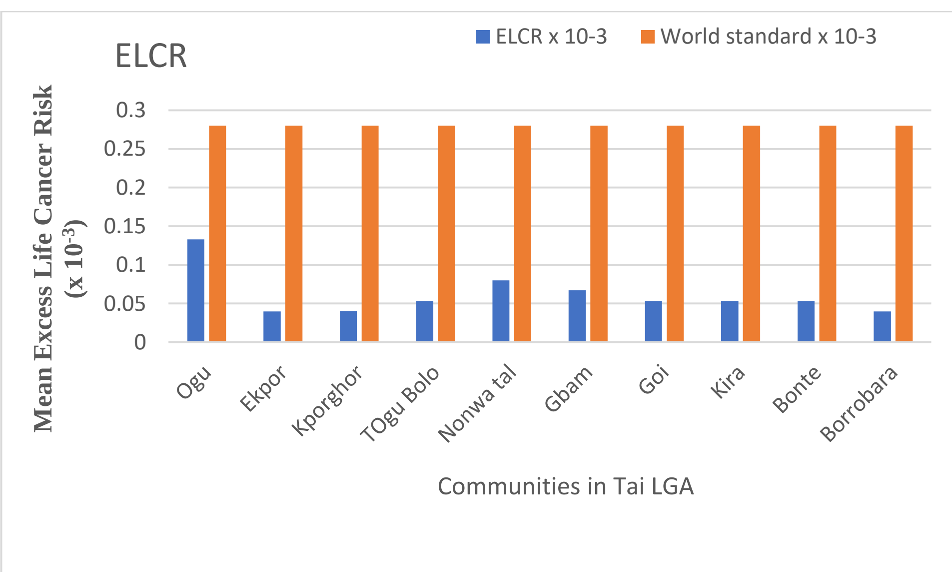

Figure 6 : **Comparison of Average ELCR in Tai LGA with World Safe Limit**

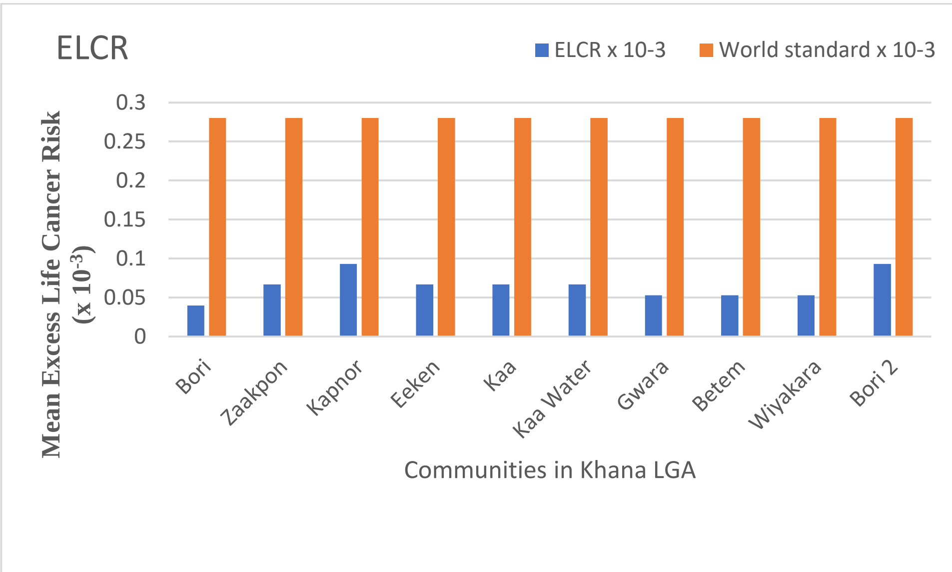

Figure 7: **Comparison of Average ELCR in Khana LGA with World Safe Limit**

The mean excess lifetime cancer risk (ELCR) of 0.215×10^{-3} (Tai) and 0.229×10^{-3} (Khana) lies below the 0.29×10^{-3} world benchmark, matches the 0.22×10^{-3} recently reported for the sedimentary terrain of Calabar, south-east Nigeria]8], but falls under the $0.31–0.35 \times 10^{-3}$ range documented for oil-spill-impacted settlements in Bayelsa [12] and Delta [5] states. Although the estimated risks are moderate, the persistent exposure still implies a non-zero probability of stochastic health effects, including radiation-induced malignancies, among the resident population

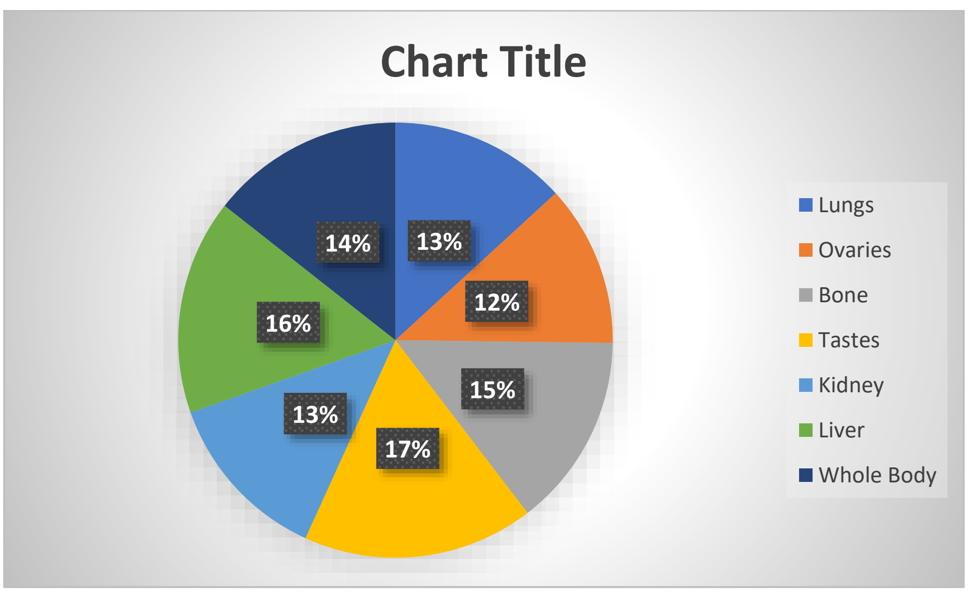

Figure 8 : **Effective dose rate to different organs / tissues**

Organ-specific effective dose rates calculated for adults peak at 0.043 mSv y^{-1} for the testes and fall to 0.030 mSv y^{-1} for the ovaries—figures that sit well below the 1.0 mSv y^{-1} organ tolerance limit [21] and match the 0.028–0.041 mSv y^{-1} range reported by [27] for Kerala's coastal sedimentary belt—confirming that background gamma exposure in the Tai and Khana communities adds only a trivial increment to adult gonadal dose.

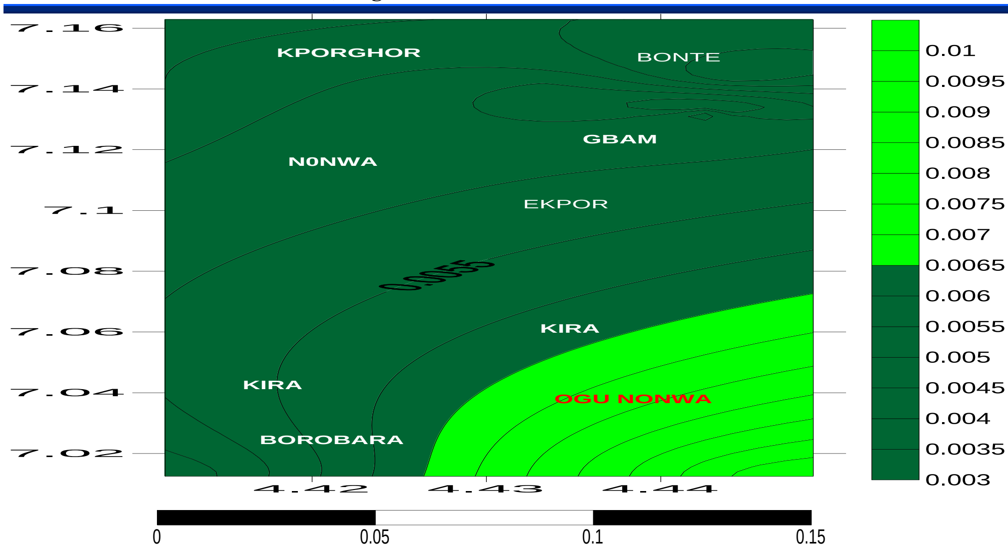

Figure 9. Contour map of communities in Tai and Khana LGA

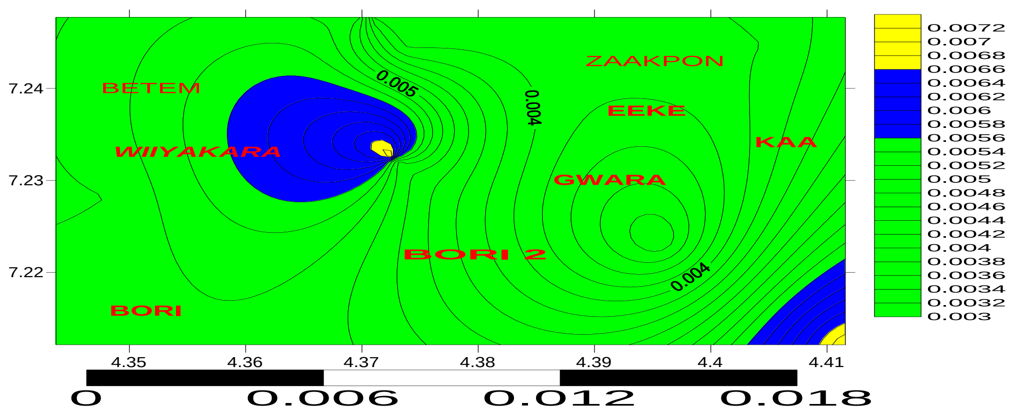

Figure 10. Contour map of communities in Khana LGA

Figure 9 and 10 displays the radiation contour map for the surveyed sectors of Tai and Khana LGAs: contour-line spacing and a blue-to-red colour scale trace the gradient from the lowest to the highest exposure rates. Tai is dominated by low-to-average levels, whereas Khana shows the reverse, an average-to-low pattern, mirroring the subdued terrestrial gamma flux typical of the Niger Delta's sedimentary belt [31].

Conclusion

A radiological reconnaissance of twenty communities in Tai and Khana LGAs (Ogoni region, Rivers State) shows that terrestrial background ionizing radiation remains within a safe band. The mean outdoor exposure is 88 % of the [44] limit, the absorbed dose rate stays 48 % below the [43] global average, and the annual effective dose (≈ 0.06 mSv) contributes only 6 % to the 1.0 mSv worldwide norm from natural sources. Likewise, the excess lifetime cancer risk peaks at 0.23×10^{-3}—25 % under the 0.29×10^{-3} world benchmark while organ-specific effective doses to testes and ovaries do not exceed 4 % of the 1 mSv y^{-1} tolerance threshold [21]. Collectively, these indices indicate that current background levels pose a negligible radiological hazard to residents of the surveyed Ogoni communities.

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