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Mapping of the Distribution of Natural Gamma Radiation (NGR) Dose Rates in Mining Areas of Nassarawa Eggon, Nasarawa, North Central Nigeria

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ABSTRACT

Natural background gamma radiation (NGR), primarily from terrestrial radionuclides uranium, thorium, and potassium, significantly contributes to human radiation exposure, with a global average effective dose of 2.4 mSv per year (UNSCEAR, 2000). Geological composition, particularly granitic rocks, influences higher NGR dose rates, necessitating localized studies to assess environmental and health impacts. This study investigates NGR levels in Nasarawa Eggon, Nasarawa State, Nigeria, an area with increasing mining activities and population growth. Using a certified Geiger-Müller counter, 150 in-situ measurements were conducted across Agidi, Akun, and Nasarawa Eggon development areas, with dose rates converted to nGy/h. The mean dose rate was 171.26 nGy/h, exceeding twice the global average of 59 nGy/h, with Agidi recording the highest (184.88 nGy/h). An isodose map, generated using QGIS and Kriging interpolation, illustrated NGR distribution. Calculated annual effective doses were 0.84 mSv (indoor) and 0.21 mSv (outdoor), below the ICRP's 1 mSv limit but above Nigerian and global averages. These findings highlight elevated NGR levels linked to local geology and mining, underscoring the need for further radiological studies to identify contributing radionuclides and ensure public safety.

Keywords:
Dose Rate,
Isodose Map,
Mean Dose Rate,
Natural Gamma Radiation.

INTRODUCTION

As a result of both cosmic and terrestrial sources, humans are continually exposed to natural background gamma radiation (Taskin et al. 2009). Human radiation exposure primarily comes from natural background radiation, with an average effective dosage of 2.4 mSv per year worldwide, as reported in the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000) report. Geographical conditions and local geology composition have a significant impact on Natural Gamma Radiation (NGR), the primary source of radiation exposure to the human body (UNSCEAR 2000). The precise concentrations and composition of the terrestrial radionuclides U, Th, and K in the crustal rocks and soils determine this in turn (Tzortzis and Tsertos 2004). Higher gamma radiation dose rates are linked to silica over saturated materials, such as granitic type igneous rocks, as opposed to other rock types, such as low-grade metamorphic and sedimentary rocks, which are known to provide low dose rates (Tzortzis et al. 2004; Sanusi et al. 2014). This is due to the high elemental concentrations of U and Th in these rocks (Faure 1986).

Globally, numerous studies have reported NGR measurements in different regions, with continuous research being conducted for various reasons (Ademola 2008; Al-Jundi 2002; Karahan and Bayulken 2000; Kurnaz 2013; Mollah et al. 1987; Rafique 2013; Ramli 2007; Ravisankar et al. 2015; Sadiq Aliyu et al. 2015; Saleh et al. 2013a, b; Sohrabi 1998).

In compliance with international standards and national requirements, the Nigerian government has enacted legislation to establish a regulatory body responsible for overseeing the use, transportation, and disposal of radioactive materials, as reported by Jibiri (2001). These can only be achieved if the baseline data on natural background radiation for its environment have been established.

This study aims to create an isodose map of Nasarawa Eggon, Nasarawa State, due to increased mining activities and population growth and to determine the annual effective dose of the study location. The data will provide a reference point to monitor radiation levels and potential environmental impacts, providing valuable information for national interest and potential future radiological mapping in Nigeria.

MATERIALS AND METHODS

Study Area

This study took place in Nassarawa Eggon LGA, located within the geographical coordinates of 8.640° - 9.180° N latitude and 7.830° - 8.640° E longitude in Nasarawa State, as shown in Figure 1. The area has an elevation of 445 meters (1,460 feet), covers 1,208 km², and had a population of 149,129 according to the 2006 census. Nassarawa Eggon features a tropical savannah climate with distinct seasonal variations, mean temperatures between 15.6°C and 26.7°C, and annual rainfall ranging from 1,317 mm to 1,450 mm (Abdullahi, 2017). The area experiences a rainy season from April to October and dry Harmattan winds from December to February (Laah & Ayiwulu, 2010). The local economy is predominantly agrarian, with a rising presence of artisanal mining activities among the communities (Onwuka et al., 2020). Nassarawa Eggon is divided into three development areas for administrative purposes.

i. Agidi Development Area (Ag),
ii. Akun Development Area (Ak) and
iii. Nassarawa Eggon (NE) as Headquarters.

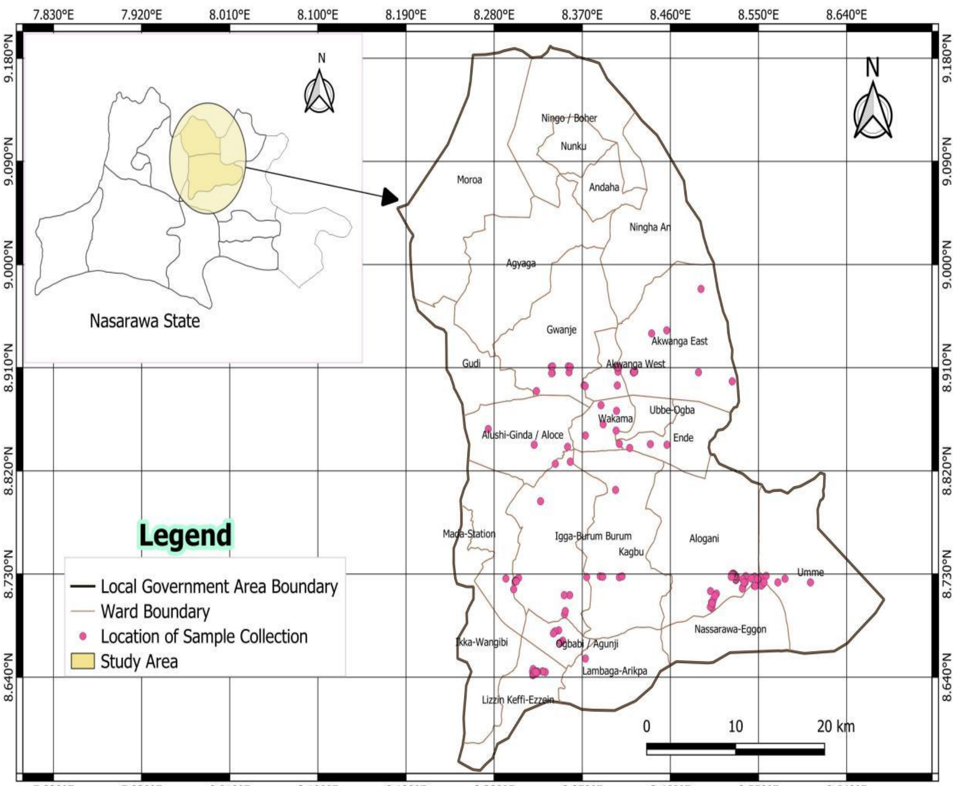

Figure 1: Sites Surveyed in Nassarawa Eggon LGA of Nasarawa State (Generated using QGIS version 3.38.3

Geology of the Study Area

The geological composition of Nasarawa Eggon, as depicted in Figure 2, includes younger granite, migmatite gneisses, basement complex rocks, and stand stones of the sedimentary succession of the middle Benue Trough, a rift basin in middle West Africa (Evans, 1980; Obaje et al., 2006). Minerals like quartz, mica, granite, lead-zinc, iron, galena ore, and gemstones (emerald, aquamarine, heliodor, topaz, and amethyst) are being extracted in several local government communities.

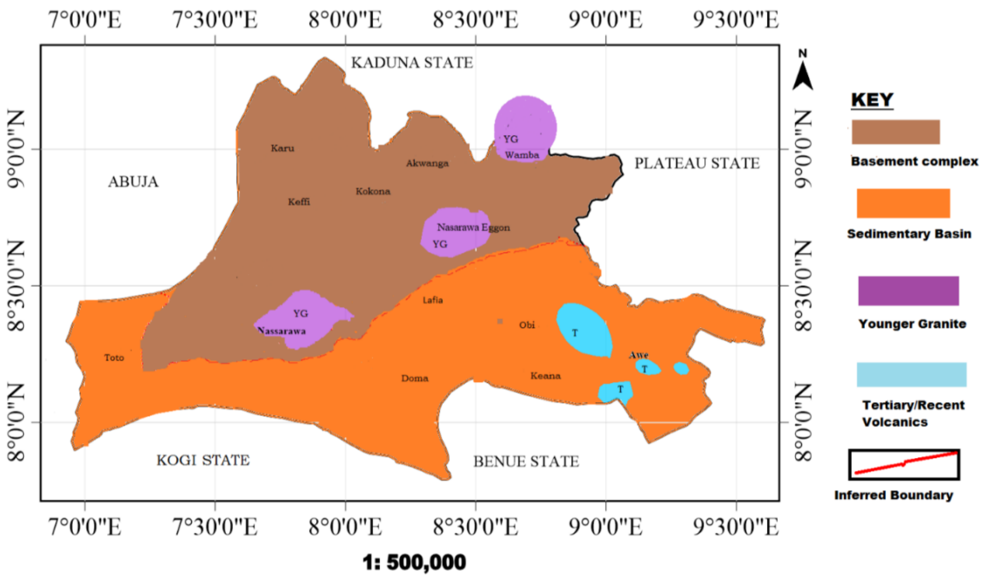

Figure 2: Geological Map of Nasarawa State (Iyakwari et al., 2020)

Background Radiation Measurement and Radiological Mapping

A certified radiation meter (GCA-07 series Geiger Counter, Images Scientific Instruments Inc., USA) was utilized to measure in-situ Natural Gamma Radiation (NGR) dose rates. Measurements were taken 1.0 m above ground level, following standard protocols (Agbalagba et al., 2016; Abba et al., 2017; Ugbede & Echeweozo, 2017). The Geiger-Müller detector tube was pre-programmed to detect background gamma radiation, with sensitivity thresholds exceeding 3.0 MeV for alpha particles, 50 keV for beta particles, and 7 keV for gamma particles. A total of 150 random measurements were conducted, with geographical coordinates recorded using GPS (version 3.13). Dose rates were displayed in μR/h and converted to nGy/h using a conversion factor (1 μR/h ≈ 8.7 nGy/h) (Ugbede et al., 2022a). To account for background radiation variability (Agbalagba, 2017; Abba et al., 2017), three repeated measurements were taken at 3-minute intervals, with the detector probe oriented towards suspected radiation sources. Measurements were made in undisturbed open fields, away from mines and mining facilities (Abba et al., 2017; Shittu et al., 2021), between 1300 and 1600 hours, when radiation meters exhibit maximum response (NCRP, 1993; Ugbede et al., 2023).

Isodose Mapping

An isodose map was generated using QGIS version 3.38.3, utilizing Natural Gamma Radiation (NGR) dose rate measurements and corresponding coordinates. The Kriging technique, a spatial interpolation method (Aziz et al., 2014; Gerrard, 2000), was employed to create the map, which represents the distribution of NGR and exposure rates in the study area. This technique uses a semi-variogram to assign weights to survey points (Apriantoro, 2008). The GPS datum was set to the World Geodetic System (WGS) 1984, ensuring synchronization with survey point coordinates. This approach is consistent with previous studies (Shittu et al., 2021; Abba et al., 2017; Hassan et al., 2015; Lee et al., 2009).

RESULTS AND DISCUSSION

Table 1 presents the NGR dose rates and corresponding coordinates for 150 points in the study area, while Table 2 provides a summary of the measured dose rates.

Table 1: Summary of the Dose Rate in Soil Samples

Label	Longitude ^{0}E	Latitude ^{0}N	Avg(nGyh^{-1})
Ag1	8.324147	8.644765	116.11
Ag2	8.324033	8.644636	109.13
Ag3	8.324147	8.644764	144.92
Ag4	8.323950	8.644897	123.09
Ag5	8.324058	8.644414	122.22
Ag6	8.324328	8.644661	181.58
Ag7	8.323936	8.644875	251.42
Ag8	8.324147	8.644764	355.31

Label	Longitude ^{0}E	Latitude ^{0}N	Avg(nGyh^{-1})
Ag9	8.323383	8.644061	389.36
Ag10	8.323813	8.643794	440.43
Ag11	8.324208	8.644717	184.38
Ag12	8.324097	8.644733	152.51
Ag13	8.323875	8.644858	206.03
Ag14	8.300000	8.716667	120.22
Ag15	8.302917	8.725003	30.01
Ag16	8.305100	8.726556	60.47
Ag17	8.302558	8.723639	245.77
Ag18	8.302264	8.723700	355.31
Ag19	8.302317	8.723733	39.43
Ag20	8.302217	8.724017	100.34
Ag21	8.302408	8.723608	321.56
Ag22	8.301822	8.723364	23.34
Ag23	8.301533	8.723519	13.67
Ag24	8.301608	8.723794	20.57
Ag25	8.302531	8.723883	176.50
Ag26	8.302747	8.723517	400.20
Ag27	8.329589	8.644906	181.20
Ag28	8.332311	8.644358	75.34
Ag29	8.329505	8.645053	80.60
Ag30	8.320150	8.644906	12.40
Ag31	8.320697	8.644339	57.12
Ag32	8.320422	8.644639	43.23
Ag33	8.322542	8.644439	511.56
Ag34	8.321431	8.644567	11.23
Ag35	8.321181	8.644803	432.11
Ag36	8.319767	8.644314	52.12
Ag37	8.319236	8.644689	68.60
Ag38	8.319597	8.641661	322.45
Ag39	8.319902	8.646994	69.78
Ag40	8.320430	8.642356	356.01
Ag41	8.340541	8.678191	587.90
Ag42	8.341347	8.679017	28.80
Ag43	8.342253	8.679969	287.13
Ag44	8.345958	8.680747	70.89
Ag45	8.347986	8.670136	234.45
Ag46	8.350014	8.671803	121.43
Ag47	8.357208	8.711525	43.69
Ag48	8.351958	8.694747	200.34
Ag49	8.352736	8.697636	307.65
Ag50	8.351653	8.711525	404.22
NE1	8.522169	8.727544	443.22
NE2	8.522469	8.729217	394.86
NE3	8.523042	8.729503	355.05
NE4	8.523378	8.730053	336.45
NE5	8.523930	8.730236	309.13
NE6	8.524153	8.730336	280.32
NE7	8.524886	8.730019	239.73
NE8	8.549294	8.725822	176.62
NE9	8.525258	8.729769	205.77
NE10	8.526356	8.728388	152.78
NE11	8.525531	8.728458	222.18
NE12	8.525922	8.728269	199.83

Label	Longitude ^{0}E	Latitude ^{0}N	Avg(nGyh^{-1})
NE13	8.549464	8.725436	183.51
NE14	8.542717	8.726050	169.87
NE15	8.527486	8.727836	137.85
NE16	8.527133	8.727463	108.25
NE17	8.527372	8.727041	111.57
NE18	8.526669	8.725742	98.04
NE19	8.527039	8.725058	92.36
NE20	8.526950	8.724738	90.44
NE21	8.501950	8.705294	55.56
NE22	8.502533	8.704489	89.12
NE23	8.503339	8.706128	32.50
NE24	8.504172	8.708072	87.22
NE25	8.505617	8.711017	143.67
NE26	8.507089	8.712842	97.32
NE27	8.501006	8.715044	67.35
NE28	8.502783	8.703433	60.31
NE29	8.502439	8.700294	70.94
NE30	8.500839	8.701294	84.45
NE31	8.546158	8.727686	58.10
NE32	8.552297	8.727408	179.23
NE33	8.557881	8.728269	228.56
NE34	8.548936	8.725714	189.17
NE35	8.545675	8.719769	207.76
NE36	8.546525	8.719475	271.00
NE37	8.548131	8.720214	185.11
NE38	8.533936	8.718491	176.45
NE39	8.533631	8.717242	183.51
NE40	8.536464	8.722658	198.14
NE41	8.545464	8.734658	199.67
NE42	8.552880	8.719908	172.00
NE43	8.554352	8.721239	322.88
NE44	8.555769	8.722742	145.65
NE45	8.569797	8.722658	244.09
NE46	8.577075	8.725881	168.61
NE47	8.603131	8.722658	178.55
NE48	8.535352	8.722631	258.22
NE49	8.533686	8.725492	172.64
NE50	8.537075	8.728056	169.78
AK1	8.406458	8.910614	443.21
AK2	8.405847	8.894519	403.23
AK3	8.389206	8.877272	391.45
AK4	8.373086	8.893947	350.44
AK5	8.405581	8.910578	274.15
AK6	8.407586	8.910344	198.23
AK7	8.357867	8.910630	205.61
AK8	8.391375	8.860613	187.43
AK9	8.355847	8.911161	167.35
AK10	8.405264	8.910613	88.11
AK11	8.406458	8.911633	102.56
AK12	8.405847	8.894519	90.78
AK13	8.389206	8.877272	201.43
AK14	8.373086	8.893947	67.66
AK15	8.405581	8.910577	126.87
AK16	8.407586	8.910344	101.24

Label	Longitude ^{0}E	Latitude ^{0}N	Avg(nGyh^{-1})
AK17	8.357867	8.910630	156.77
AK18	8.391375	8.860613	142.01
AK19	8.355847	8.911161	45.14
AK20	8.405264	8.910613	50.23
AK21	8.406550	8.906550	144.23
AK22	8.405058	8.872336	49.0
AK23	8.404606	8.855086	89.07
AK24	8.404069	8.803308	174.88
AK25	8.355058	8.840947	201.55
AK26	8.327463	8.793463	220.67
AK27	8.320966	8.842772	195.00
AK28	8.373244	8.850883	158.81
AK29	8.342550	8.826077	267.81
AK30	8.292022	8.725994	250.65
AK31	8.274022	8.856466	70.00
AK32	8.418522	8.839966	106.12
AK33	8.373272	8.656244	93.11
AK34	8.440883	8.939883	74.15
AK35	8.456272	8.942550	186.72
AK36	8.491328	8.978716	156.31
AK37	8.523217	8.898086	93.00
AK38	8.456550	8.842741	107.45
AK39	8.439600	8.843302	133.91
AK40	8.356550	8.905983	41.22
AK41	8.339319	8.905422	60.43
AK42	8.338731	8.905138	57.88
AK43	8.323272	8.889577	80.67
AK44	8.488761	8.905972	23.45
AK45	8.422383	8.905716	66.78
AK46	8.422103	8.906252	103.00
AK47	8.423775	8.906552	36.44
AK48	8.422375	8.906541	62.13
AK49	8.423192	8.9065277	37.90
AK50	8.433141	8.9265267	213.00

Table 2: Summary of the Basic Statistics for External Gamma Dose Rates

Statistics	Dose Rate (nGy/h)
Mean	171.26
Range	11.23 – 587.90
SE	9.63
SD	117.13
Median	154.54
Mode	443.2
World Average	59

Note: SE= Standard Error, SD = Standard Deviation

The mean outdoor dose rate measurement was 171.26 nGy/h, with a range of 11.23 to 587.90 nGy/h, exceeding twice the global average of 59 nGy/h reported by UNSCEAR (2000). Notably, the highest dose rate was recorded in Ag41, characterized by granitic rock formations, while the lowest dose rate was observed in Ag34, with sandstone, clay, and shale formations. This disparity is consistent with existing literatures, which suggests that soils derived from granitic parent material tend to exhibit higher dose rates due to the presence of uranium and thorium-bearing minerals (UNSCEAR, 2000; Sanusi et al., 2014; Abba et al., 2017). The findings of this study align with previous research, which reported elevated dose rates in soils of igneous origin (Ramli et al., 2009; Lee, 2009; Garba et al., 2015). Conversely, lower dose rates have been reported in soils derived from sedimentary rocks (Tzortzis et al., 2004). A comparison with global averages and other studies (Table 3) reveals that the total mean dose rate in the surveyed area is not only more than twice the world average but also higher than that of other regions (Olarinoye et al., 2010; Jibiri et al., 2016; Faanu et al., 2016; Abba et al., 2017; Shittu et al., 2021; Ofomola et al., 2023).

Table 3: Mean Dose Rate for this Study Compared to Other Countries of the World

S/N	Country/Region	Dose Rate (nGy/h)	Reference
1	Spain	76	UNSCEAR (1988)
2	Portugal	84	UNSCEAR (2000)
3	USA	47	UNSCEAR (2000)
4	India	56	UNSCEAR (2000)
5	Brazil	125	Freitas and Alencar (2004)
6	Jos Plateau	13,500	Ademola (2008)
7	Iran	105	Baykara and Dogru (2009)
8	Minna	154	Olarinoye et al., (2010)
9	Malaysia	209	Nuraddeen et al., (2015)
10	Ghana	741	Faanu et al., (2016)
11	Southwest, Nigeria	232	Jibiri et al., (2016)
12	Jos Plateau	250	Abba et al., (2017)
13	Gidan-Kwano, Minna	136.75	Shittu et al., (2021)
14	Southeastern Nigeria	12.21	Ofomola et al., (2023)
15	Nassarawa Eggon	171.26	This study

However, it was discovered that the values in this study were lower than those mentioned by Ademola (2008), Jibiri et al. (2016), Abba et al. (2017) in the same region, Faanu et al. (2016) for Ghana's central region, and Ramli et al. (2009) for Malaysia's Selama district. The decades-long environmental effects of mining operations have been shown to increase background radiation levels inside mines and near mining and processing facilities in some mining locations (Farai and Jibiri 2000; Jibiri et al. 2007a, 2009; Jwanbot et al. 2013). This may be the reason for the higher dose rate values observed in a few locations.

Figure 3. shows the Histogram for dose rates for the three development areas of the study area.

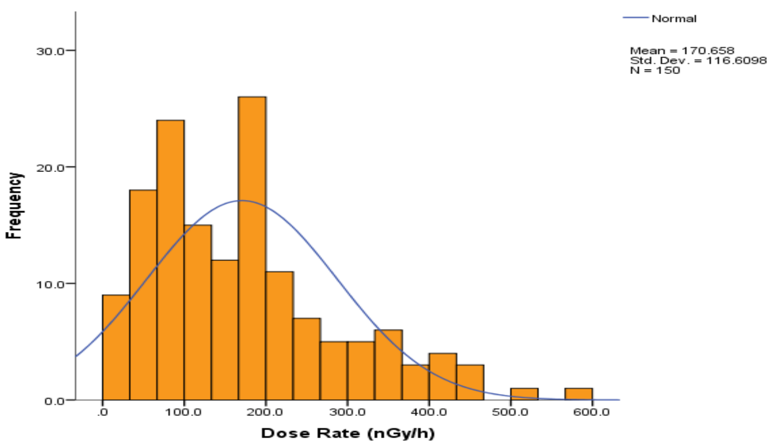

Figure 3: Histogram for Dose Rates

The frequency distribution histogram showed that between 156.3 and 587.9nGyh-1, 50% of the observed dose rates fell within this range. Due to the large concentration of basement complex rocks and younger granites in certain regions, the study area's NGR distribution is primarily influenced by human activity and basement rocks. Higher dosage rates, for example, were noted at the Agidi Development Area. This is consistent with research done in Nigeria by Joel et al. (2019) and the Central Nubian shield of Egypt by Heikal et al. (2019).

The mean values of the dose rates for the three development areas are presented in Fig.4

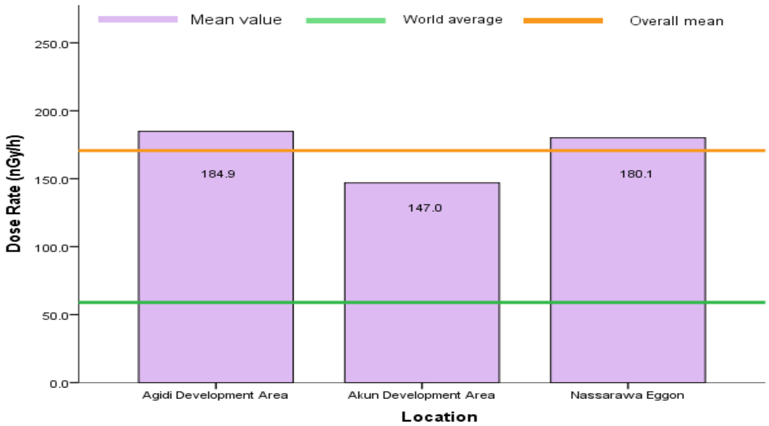

Figure 4: Mean Value of Dose Rates for the Three Development Areas of the Study Area

The two solid horizontal lines show the difference between the results and the study's overall mean value as well as the global average. It was found that Agidi Development Area had the greatest mean dose rate (184.88±21.13 nGyh-1). In the Akun Development Area, the mean dose rate was the lowest at 147.0 ± 17.12 nGy^{-1}.

Isodose Mapping of the Study Area

Figures 5. shows the Isodose map of the entire study area with the highest mean dose rate (184.88±21.13 $nGyh^{-1}$) recorded at Agidi Development Area. The lowest mean dose rate (147.0 ± 17.12 nGy h^{-1}) was observed in Akun Development Area

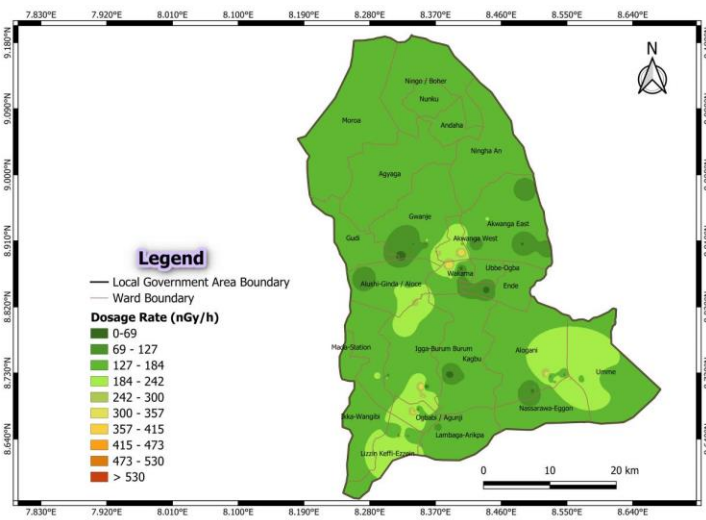

Figure 5: Isodose Map for the Study Area. (Generated Using QGIS Version 3.38.3)

Determination of Annual Effective Dose (AED)

Mean indoor and outdoor yearly effective doses from exposure to natural sources of background gamma radiation were calculated using the acquired mean dose rate. In order to determine the parameters, the UNSCEAR (2000) recommended indoor and outdoor occupancy factors of 0.8 and 0.2, respectively, and a conversion coefficient of 0.7 Sv Gy-1 for the absorbed dose in air to effective dose. The indoor and outdoor annual effective dose equivalent was estimated using Equation 1 and 2, respectively.

AED_{in} (mSv/y) = mean dose rate (nGy/h) x 24(h) x 365(days) x 0.8 x 0.7 x 10^{-6} (1)

AED_{ext}(mSv/y) = mean dose rate (nGy/h) x 24(h) x 365(days) x 0.2 x 0.7 x 10^{-6} (2)

Based on an assumed 20% occupancy factor (UNSCEAR, 2000), the calculated outdoor annual effective dose (AED) is 0.21 mSv, which falls below the recommended limit of 1 mSv set by the International Commission on Radiation Protection (ICRP, 1990). However, this value exceeds the Nigerian average of 0.098 mSv (Farai & Jibiri, 2000; Aliyu et al., 2015; Abba et al., 2017) and the global average of 0.07 mSv (UNSCEAR, 2000). In contrast, the estimated indoor AED of 0.840 mSv surpasses the worldwide average of 0.46 mSv (UNSCEAR, 2000). Comparison with regional studies reveals that the mean outdoor AED is consistent with findings by Mohammed et al. (2021) but higher than values reported by Ibrahim et al. (2013) and Kerinja et al. (2020). Notably, the calculated AED values are within permissible limits, suggesting no significant radiological health concerns for the local population.

CONCLUSION

This investigation reveals that the study area's elevated background radiation levels are attributable to natural terrestrial and cosmic sources. The computed mean dose rate of 171.26 nGy/h, with a standard deviation of 117.13 nGy/h, exceeds twice the global average of 59 nGy/h reported by UNSCEAR (2000), positioning it within the highest range of worldwide measurements. The estimated mean annual effective doses for the public are 0.840 mSv/y (indoor) and 0.21 mSv/y (outdoor), both below the recommended dose limit set by the ICRP. Utilizing QGIS software, an isodose map was generated to illustrate the distribution of natural gamma radiation and exposure rates across the study area. Given the findings, a comprehensive radiological study is warranted to identify the specific radionuclides contributing to the elevated gamma dose rates in the region.

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