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In Situ Determination of Radioactivity Levels and Annual Effective Dose Rate from Soil Samples around the Gosa Dumpsite in FCT, Abuja

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Abstract- ***Open dumpsites represent a potentially significant source of elevated ambient gamma radiation in peri-urban environments due to the heterogeneous composition of municipal solid waste deposited at such facilities. This study presents in situ measurements of ambient gamma dose rates, annual absorbed doses (AD), and annual effective doses (AED) in soils at the Gosa dumpsite, Federal Capital Territory (FCT), Abuja, Nigeria. Measurements were conducted at six dumpsite soil points (PT1–PT6) and one background control soil site using two independently calibrated radiation survey meters — the RADEYE G20-10 and the RADOS RDS-120. The mean dose rate (MDR) across the dumpsite ranged from 0.11 to 0.17 μSv/h (mean 0.13 ± 0.02 μSv/h), corresponding to absorbed dose rates of 110–170 nGy/h. The annual effective doses ranged from 0.1349 to 0.2085 mSv/y (mean 0.1533 ± 0.0245 mSv/y). The background control soil site recorded a dose rate of 0.06 μSv/h and an AED of 0.0736 mSv/y. Percentage errors between the two instruments ranged from 0.00% to 42.86% (mean 18.53%), consistent with expected Geiger-Müller instrument variability in heterogeneous field conditions. All measured annual effective doses remained well below the 1 mSv/y public dose limit recommended by the International Commission on Radiological Protection (ICRP). These results constitute the first baseline radiological dataset for the Gosa dumpsite and underscore the need for periodic monitoring and improved solid waste governance in the FCT.***

Keywords: in situ gamma dose rate; annual effective dose; absorbed dose; Gosa dumpsite; RADEYE G20-10; RADOS RDS-120; soil radioactivity; FCT Abuja; NORMs

I. INTRODUCTION

Naturally occurring radioactive materials (NORMs) are ubiquitous components of the soil environment and constitute the dominant source of natural background radiation received by the general public worldwide [1]. The ambient gamma dose rate at any soil surface primarily reflects the integrated contribution of the uranium-238 (^{238}U) and thorium-232 (^{232}Th) decay series, together with potassium-40 (^{40}K), from the soil at and below the measurement point [2]. The annual effective dose (AED) derived from external gamma irradiation is the principal dosimetric quantity used for regulatory assessment of public exposure, as it accounts for the tissue-weighting factors assigned to different organs of the human body [14]. Both natural and anthropogenic sources contribute to human radiation exposure; industrial, medical, and waste-related activities can introduce additional radionuclides into the environment, supplementing the natural radiation background [17]. Under undisturbed natural conditions, soil radioactivity and the resulting AED are governed primarily by the geochemical composition of the parent material. However, anthropogenic activities that introduce exogenous materials into the soil — including the deposition of municipal solid waste — can significantly perturb the local radiation field and elevate AED values above natural background levels [3].

Prolonged exposure to naturally occurring radionuclides in soil poses potential radiological health risks to the general population. Natural radiation forms a major component of the total annual radiation exposure to humans [2]. Extended exposure to ionising radiation can cause biological effects ranging from DNA strand breaks to cellular and molecular damage [25]. Exposure to uranium and thorium series radionuclides and their decay progeny is associated with health hazards including pulmonary effects, renal toxicity, and increased risk of bone and lung cancer [26, 27]. The activity concentrations of natural radionuclides in soils vary with the lithological and geochemical character of the underlying parent material [20, 28].

Open dumpsites, where municipal solid waste (MSW) is deposited directly onto the ground without engineered containment, remain the most prevalent mode of solid waste disposal across sub-Saharan Africa [4]. The decomposition of waste and infiltration of rainwater through the waste body generates leachate that mobilises radionuclides into surrounding soils [5], potentially leading to dose rates and AED values above the local geogenic background. Communities residing adjacent to such facilities — particularly informal waste pickers — may therefore receive elevated annual effective doses from external gamma radiation [6].

Nigeria generates more than 32 million tonnes of solid waste annually, of which only 20–30% is collected [7]. Inadequate solid waste collection leads to blockage of drainage networks, contamination of water bodies, and increased public health risks in urban areas [9]. Most waste is generated by households and, in some cases, by local industries, artisans, and traders, resulting in littering of the immediate surroundings [7]. The Federal Capital Territory (FCT), Abuja, has experienced rapid urbanisation over the past two decades, placing growing pressure on waste management infrastructure. The Gosa dumpsite, located in the southern periphery of the FCT Municipal Area Council (Figure 5), is one of the city's primary waste disposal facilities, surrounded by expanding informal residential settlements.

This study therefore aimed to: (i) determine the in situ ambient gamma dose rate in soils at the Gosa dumpsite and a background control soil site using the RADEYE G20-10 and RADOS RDS-120; (ii) calculate the absorbed dose rate (D), annual effective dose (AED), and percentage error between instruments at each point; (iii) compare values against international reference levels and regulatory limits; and (iv) establish a baseline radiological dataset for the FCT.

1.1. Study Area

The Gosa dumpsite is situated in the Gosa district of the Municipal Area Council (MAC), FCT, Abuja, Nigeria, at approximately within Latitude 8.9833° N and Longitude 7.3667° E. (Figure 5). The facility covers an estimated area of approximately 15 hectares and has been in continuous operation since the early 2000s, currently receiving an estimated 400–600 tonnes of MSW per day (field survey, 2025). The dumpsite is bounded to the south by a seasonal stream and to the north, east, and west by residential settlements and cultivated farmland (field survey, 2025). Waste categories received include domestic refuse, construction and demolition debris, biomedical waste, and discarded electronic equipment (field survey, 2025). Informal waste pickers are regularly present on the active tipping face. It is one of the largest waste disposal facilities in the FCT, receiving a high volume of municipal and industrial waste. The site has been reported to pose risks of groundwater and soil contamination due to uncontrolled waste disposal practices.

The soils of the FCT are predominantly derived from the weathering of Precambrian basement complex parent materials and are generally classified as sandy loams to clay loams with moderate organic matter content [11]. These soils exhibit moderate natural background radioactivity levels consistent with their basement complex parent material geochemistry [11, 20]. The climate is tropical savanna (Köppen Aw), with mean annual rainfall of approximately 1,500 mm and a mean annual temperature of 29 °C [NiMet, 2020].

II. MATERIALS AND METHODS

2.1. In Situ Gamma Dose Rate Survey

In situ measurement of ambient gamma dose rates is a widely applied technique for environmental radiological surveys, providing a direct assessment of the external radiation dose to which persons present at a given soil surface are exposed [2, 9]. In this study, in situ measurements of ambient gamma dose rates in soils at the Gosa dumpsite were undertaken using two portable, calibrated radiation survey meters: the RADEYE G20-10 (Thermo Fisher Scientific, Waltham, MA, USA)[12] and the RADOS RDS-120 (Mirion Technologies, Atlanta, GA, USA)[13]. Both instruments employ energy-compensated Geiger-Müller detector technology calibrated to measure ambient dose equivalent rate H*(10) in μSv/h. The RADEYE G20-10 has a measurement range of 0.01-100 〖μSvh〗^(-1), energy response of 50 keV-1.3 MeV (±30%), and overall accuracy of ±15% [12]. The RADOS RDS-120 has a range of 0.01–9.99 μSv/h, energy response

of 40 keV–3 MeV, and calibration uncertainty of ±10% [13]. Concurrent deployment of both instruments enabled cross-validation of readings and quantification of inter-instrument variability, expressed as a percentage error at each measurement point. Both instruments were verified against a certified reference source prior to fieldwork and confirmed to be within their factory-specified calibration validity periods.

In situ measurements were conducted at seven soil locations: six points distributed across the active dumpsite soil surface (PT1–PT6) and one background control soil site approximately 1.5 km from the dumpsite boundary, in an area free from waste disposal activities (Figure 5). At each point, both instruments were held simultaneously at a standard height of 1 m above the soil surface, in accordance with ICRU and IAEA protocols for environmental gamma dose rate surveys [2, 10]. The RADEYE G20-10 reading is designated RG and the RADOS RDS-120 reading is designated RR. The mean dose rate (MDR) was calculated as the arithmetic mean of the two readings, with uncertainty expressed as half the absolute difference between them. Geographic coordinates of each point were recorded using a hand-held GPS receiver.

2.2. Calculation of Percentage Error

To assess the agreement between the two instruments, the percentage error at each measurement point was calculated using Equation (1), following the calibration and measurement uncertainty protocol described in Moshupya et al. [15], which mirrors standard practice in analogous in situ radiological surveys:

$$Error\,(\%) = \left(\frac{RG - RR)}{RG}\right) \times 100 \quad (1)$$

where RG is the reading of the RADEYE G20-10 (taken as the reference value) and RR is the reading of the RADOS RDS-120. The overall measurement error, accounting for instrument accuracy and field geometry, was estimated at ±15%.

2.3. Calculation of Absorbed Dose Rate

The outdoor absorbed dose rate in air (D) at 1 m above the soil surface was obtained directly from the measured MDR values. Since the instruments are calibrated in μSvh^{-1} and $1\ \mu Svh^{-1} \approx 1\ \mu Gyh^{-1}$ for gamma photons (radiation weighting factor WR = 1), the absorbed dose rate in $nGyh^{-1}$ is obtained by unit conversion, following IAEA [9] and UNSCEAR [2] conventions:

$$D\,(nGy\,h^{-1}) = MDR\,(\mu Sv\,h^{-1}) \times 1000 \quad (2)$$

2.4. Calculation of Annual Effective Dose

The annual effective dose (E) was estimated from the absorbed dose rate (D) using the dose conversion factor of $0.7\ Sv\ Gy^{-1}$, an outdoor occupancy factor of 0.2, and an annual exposure duration of 8760 h, as expressed in Equation (3). This is the universally adopted formula recommended by UNSCEAR for estimation of annual effective dose from external terrestrial gamma radiation [2], and is the same formula applied in Moshupya et al. [15] and consistently used across peer-reviewed in situ radiological surveys [1, 6]:

$$E\,(mSv\,y^{-1}) = D\,(nGy\,h^{-1}) \times 0.2 \times 8760\,(h) \times 0.7\,(Sv\,Gy^{-1}) \times 10^{-6} \quad (3)$$

where D is the absorbed dose rate in nGy/h; 0.2 is the outdoor occupancy factor (OF) representing the fraction of time an average member of the public spends outdoors [2]; 8760 is the total number of hours per year; $0.7\ Sv/Gy$ is the dose conversion coefficient from absorbed dose in air to effective dose in the human body from external gamma irradiation [2]; and 10^{-6} is the unit conversion factor $nGy \rightarrow Gy;\ \mu Sv \rightarrow mSv$. All calculated AED values were compared against the UNSCEAR global average AED from external terrestrial gamma radiation in soil (0.041 mSv/y) [2] and the ICRP public dose limit of 1 mSv/y [14].

III. RESULTS

3.1. In Situ Dose Rate Measurements and Percentage Error

The complete in situ ambient gamma dose rate measurements, percentage errors, and derived dosimetric quantities at all seven soil locations are presented in Table 1. Figure 1 shows a side-by-side comparison of RG and RR readings at all seven locations. The RADEYE G20-10 readings (RG) at the six dumpsite soil points ranged from 0.11 to 0.21

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µSv/h, while the concurrent RADOS RDS-120 readings (RR) ranged from 0.10 to 0.12 $\mu Sv h^{-1}$.

The percentage errors calculated using Equation (1) ranged from 0.00% (PT6 and the Control Site) to 42.86% at PT2 (Figure 4). At PT1, PT3, and PT5, errors were $8.33 - 16.67\%$, within or near the combined instrument accuracy range of ±15%. PT4 recorded 26.67%. With the exception of PT2, these errors reflect expected inter-instrument variability for this class of survey meters in heterogeneous soil environments. The anomalously large error at PT2 (42.86%) is attributed to localised heterogeneity in the waste-soil matrix at that point.

Table 1. In situ ambient gamma dose rates (RG = RADEYE G20-10; RR = RADOS RDS-120), mean dose rate (MDR), percentage error in Eq. 1[15], absorbed dose rate D in Eq. 2 [2, 9], and annual effective dose E in Eq.3 [2] at the Gosa dumpsite and background control soil site, FCT, Abuja.

No.	Location	RG (µSv/h)	RR (µSv/h)	MDR (µSv/h)	Error (%) [Eq.1]	D (nGy/h) [Eq.2]	E (mSv/y) [Eq.3]
1	PT1	0.12	0.11	0.12 ± 0.01	8.33	120	0.1472 ± 0.0123
2	PT2	0.21	0.12	0.17 ± 0.05	42.86	170	0.2085 ± 0.0613
3	PT3	0.12	0.10	0.11 ± 0.01	16.67	110	0.1349 ± 0.0123
4	PT4	0.15	0.11	0.13 ± 0.02	26.67	130	0.1594 ± 0.0245
5	PT5	0.12	0.10	0.11 ± 0.01	16.67	110	0.1349 ± 0.0123
6	PT6	0.11	0.11	0.11 ± 0.00	0.00	110	0.1349 ± 0.0000
7	Control Site	0.06	0.06	0.06 ± 0.00	0.00	60	0.0736 ± 0.0000
	Minimum	0.06	0.06	0.06	0.00	60	0.0736
	Maximum	0.21	0.12	0.17	42.86	170	0.2085
	Dumpsite Mean	0.14	0.11	0.13 ± 0.02	18.53	130	0.1533 ± 0.0245
	UNSCEAR Avg. [2]	—	—	0.067	—	59	0.041
	ICRP Limit [14]	—	—	—	—	—	1.000

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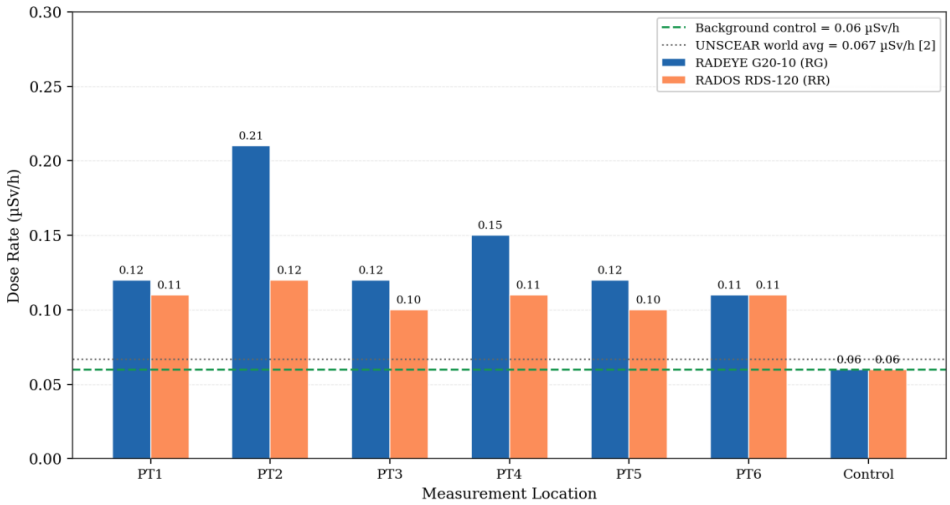

Figure 1. Comparison of RADEYE G20-10 (RG) and RADOS RDS-120 (RR) dose rate readings at all measurement locations. The dashed green line indicates the background control value (0.06 µSv/h); the dotted grey line indicates the UNSCEAR world average (0.067 µSv/h) [2].

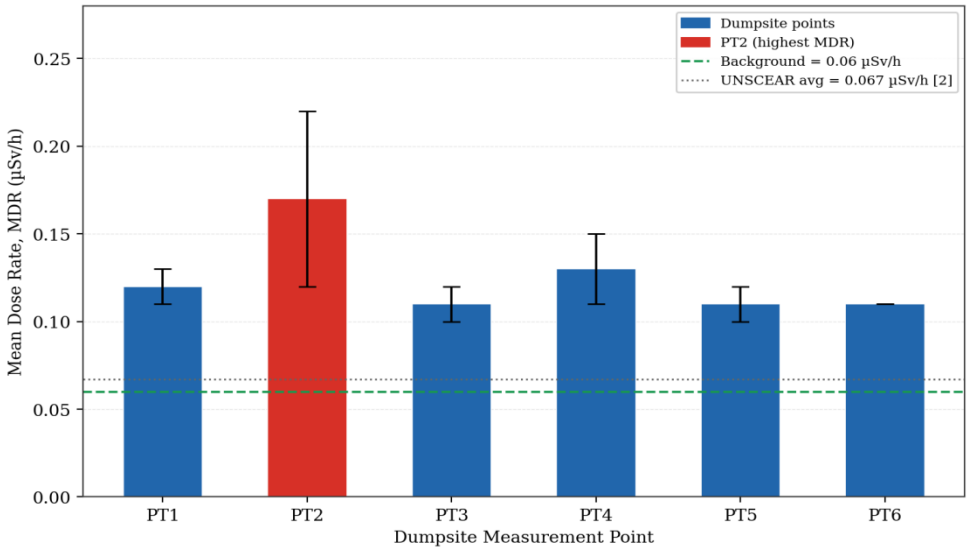

Figure 2. Mean dose rate (MDR ± uncertainty) at dumpsite soil measurement points (PT1–PT6). PT2 (red) records the highest MDR of 0.17 ± 0.05 µSv/h, approximately 2.8 times the background. Reference lines indicate the background control value and UNSCEAR world average [2].

3.2. Absorbed Dose Rate in Air

The outdoor absorbed dose rate (D) calculated from the MDR values using Equation (2) [2, 9] ranged from $60\ \mathrm{nGyh^{-1}}$ at the background control soil site to $170\ \mathrm{nGyh^{-1}}$ at PT2 (Table 1). The global mean absorbed dose rate in ambient air from terrestrial gamma radiation is reported as $59\ \mathrm{nGyh^{-1}}$ by UNSCEAR [2]. The absorbed dose rates at all dumpsite soil points $110 - 170\ \mathrm{nGyh^{-1}}$ exceeded this global mean, while the background control site (60 nGy/h) was in close agreement, confirming the suitability of the control site as a representative local background.

3.3. Annual Effective Dose

The annual effective doses (E) calculated using Equation (3) [2] at dumpsite soil points ranged from $0.1349 \pm 0.0123\ \mathrm{mSvy^{-1}}$ (PT3, PT5, PT6)

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to $\llbracket 0.2085 \pm 0.0613\ \mathrm{mSvy}^{-1}$ (PT2), with a dumpsite mean of $0.1533 \pm 0.0245\ \mathrm{mSvy}^{-1}$ (Table 1, Figure 3). The background control site yielded an AED of 0.0736 mSv/y. The dumpsite mean AED of $0.1533\ \mathrm{mSvy}^{-1}$ is approximately 2.1 times the background value $0.0736\ \mathrm{mSvy}^{-1}$ and represents 15.3% of the ICRP public dose limit of $1\ \mathrm{mSvy}^{-1}$. Even at the highest measured point (PT2: $0.2085\ \mathrm{mSvy}^{-1}$), the AED remains at 20.9% of the regulatory limit. All measured annual effective doses are therefore well below the 1 mSv/y threshold.

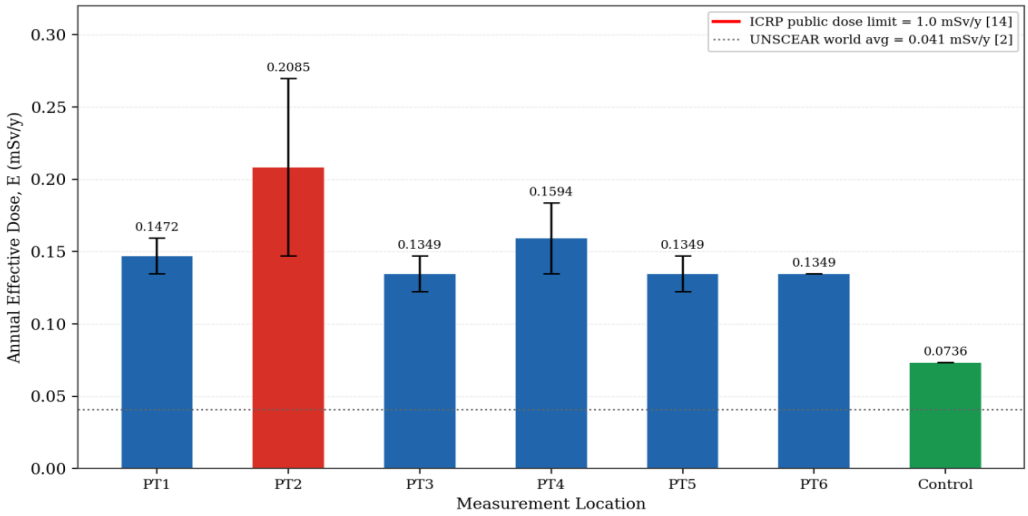

Figure 3. Annual effective dose (E ± uncertainty) calculated using Equation (3) [UNSCEAR 2000. [2] at all measurement locations. The solid red line indicates the ICRP public dose limit (1.0 mSv/y) [14]. All values are well below the regulatory limit.

3.4. Percentage Error Analysis

Figure 4 presents the percentage errors between the RADEYE G20-10 and RADOS RDS-120 readings at each location, calculated using Equation (1) [15]. PT6 and the Control Site recorded 0.00% error. PT1 (8.33%), PT3 (16.67%), and PT5 (16.67%) showed errors within or near the combined instrument accuracy range of ±15%. PT4 recorded 26.67%. PT2 recorded the highest error of 42.86%, reflecting localised waste-soil heterogeneity at that measurement point. The overall mean percentage error across all dumpsite points was 18.53%, consistent with the manufacturer-specified combined accuracy range for this class of instruments in heterogeneous field conditions.

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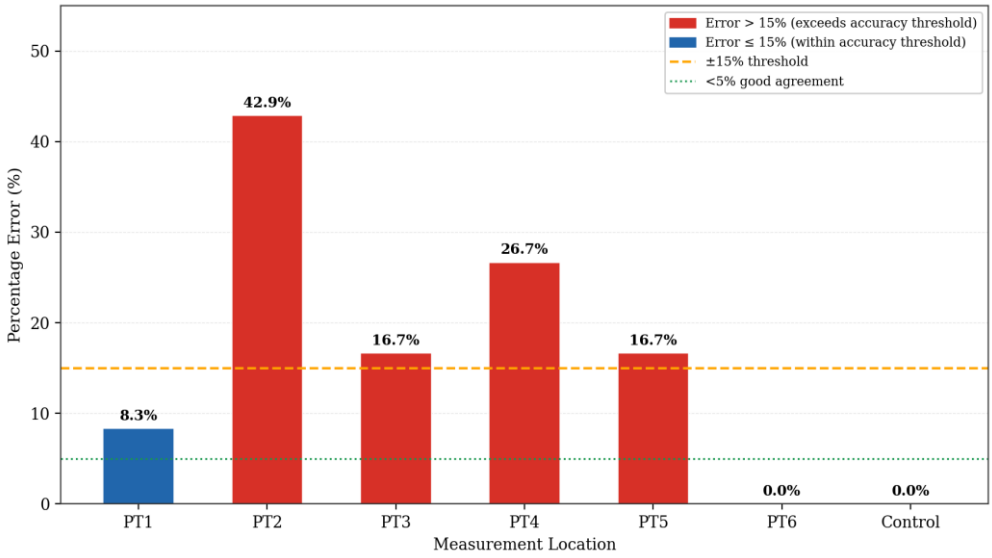

Figure 4. Percentage error in Eq. 1 [15] between RADEYE G20-10 (RG) and RADOS RDS-120 (RR) readings at all measurement locations. Red bars indicate errors exceeding the ±15% instrument accuracy threshold. PT2 records the largest discrepancy (42.86%), attributed to localised waste-soil heterogeneity.

IV. DISCUSSION

The mean annual effective dose in dumpsite soils (0.1533 ± 0.0245 mSv/y), calculated using Equation (3) [2], was approximately 2.1 times the background control soil AED (0.0736 mSv/y) and above the UNSCEAR global average of 0.041 mSv/y for undisturbed soils [2]. This moderate elevation is consistent with published AED values from comparable MSW dumpsite and waste-impacted soil environments, where dumpsite soil AED values of 0.06–0.15 mSv/y have been reported in similar West African and tropical settings [6, 19, 22]. The elevation is attributed to accumulation in dumpsite soils of gamma-emitting radionuclides from waste materials — particularly construction and demolition debris enriched in uranium and thorium, and electronic waste components with elevated radionuclide concentrations [3, 5].

It is noted that the background control site AED (0.0736 mSv/y) is approximately 1.8 times the UNSCEAR global average of 0.041 mSv/y for undisturbed soils [2]. This is consistent with the generally elevated natural background radioactivity levels characteristic of soils derived from Precambrian basement complex parent materials in north-central Nigeria, which typically exhibit higher uranium and thorium concentrations than the global soil average [11, 20]. This elevated background further underscores that the additional radioactivity attributable to waste deposition represents an anthropogenic perturbation above an already moderately elevated natural baseline.

The large percentage error at PT2 (42.86%), calculated using Equation (1), and the corresponding elevated AED of 0.2085 mSv/y at this point highlight the importance of deploying two independent instruments concurrently. At all other points, percentage errors were 0.00–26.67%, consistent with known inter-instrument variability for energy-compensated Geiger-Müller survey meters in field conditions. Although all measured AED values are well below the ICRP 1 mSv/y limit [14], informal waste pickers working approximately 8 hours per day, 5 days per week (OF ≈ 0.24) at PT2 could receive an AED of approximately 0.36 mSv/y — still within regulatory limits but warranting a dedicated occupational dose assessment. A key limitation is that energy-compensated Geiger-Müller measurements do not resolve individual contributions of ^{238}U, ^{232}Th, and ^{40}K; future gamma ray spectrometric measurements of dumpsite soil samples are therefore recommended. External gamma radiation also represents only one of several exposure pathways; radon inhalation and ingestion of contaminated groundwater are additional dose contributions not captured in this study [1].

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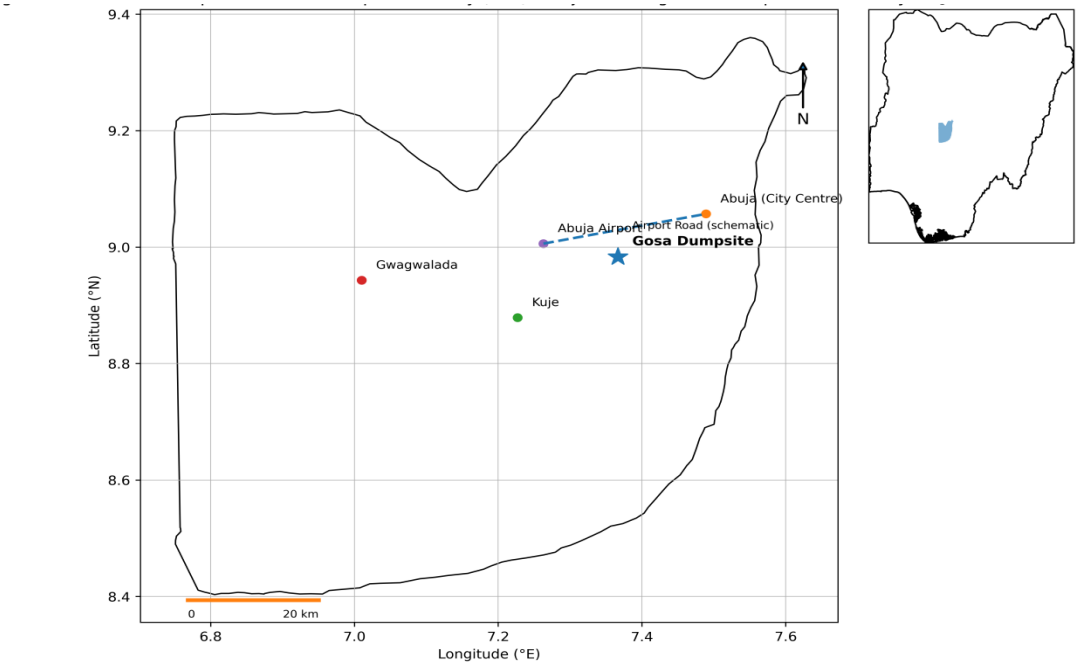

Fig 5: AGIS derived map of Federal Capital Territory(FCT) showing Gosa Dumpsite[18]

V. CONCLUSIONS

This study presents the first in situ radiological characterisation of soil at the Gosa dumpsite, FCT, Abuja, Nigeria, using the RADEYE G20-10 and RADOS RDS-120 concurrently at six dumpsite points and one background control site. The principal conclusions are:(i) Ambient gamma dose rates in dumpsite soils (MDR: 0.11–0.17 µSv/h; mean 0.13 ± 0.02 µSv/h) corresponded to absorbed dose rates of 110–170 nGy/h (Eq. 2) [2, 9], 1.8–2.8 times the background control value (60 nGy/h). (ii) Annual effective doses in dumpsite soils (E: 0.1349–0.2085 mSv/y; mean 0.1533 ± 0.0245 mSv/y), calculated using the UNSCEAR formula (Eq. 3) [2], are well below the ICRP public dose limit of 1 mSv/y [14]. (iii) Percentage errors between the two instruments (Eq. 1) [15] ranged from 0.00% to 42.86% (mean 18.53%), consistent with the expected accuracy of Geiger-Müller instruments in heterogeneous field conditions. (iv) The background control site AED (0.0736 mSv/y) was elevated relative to the UNSCEAR global average (0.041 mSv/y) [2], consistent with the naturally elevated radioactivity of Precambrian basement complex soils in the FCT.

Recommended follow-up actions: (a) periodic radiological soil monitoring integrated into the FCT environmental monitoring framework; (b) gamma ray spectrometry of dumpsite soil samples to determine ^{238}U, ^{232}Th, and ^{40}K activity concentrations and their relative contributions to the measured AED; (c) radon soil gas measurements and shallow groundwater sampling to characterise additional dose pathways; and (d) occupational dose assessment for waste pickers using actual site occupancy data.

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Conflicts of Interest: The authors declare no conflict of interest.

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