

Review Article

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Determination of Radon-222 Concentration in Soil Samples from VI, Shaffa and Garta Sama Communities of Michika Local Government Area, Adamawa State, Nigeria

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ABSTRACT

Radon-222 and its progeny contributed greatly to natural background radiation. Long time exposure to radiation increases the high probability of cancer to persons, radiological hazard associated with inhalation of radon-22 gas from 25 soil samples were collected and analysed for radon using RAD7 electronic detector. The research measured soil-gas radon-222 activity concentration, absorbed dose rate, annual effective dose equivalent and excess lifetime cancer risk at five sampling points (VI-East, VI-West, VI-South, Garta sama-South, and Shaffa- South) at 50m, 100m, 200m, 500m and 2km from artisanal mining pit. Radon-222 concentrations ranged from 257 – 6,438 Bq/m³ across all sampling points and distance. Four out five points exceeded the ICRP reference level (300 Bq/m³) and WHO screening limit (100 Bq/m³) at every distance sampled, including the 2km control zone. AEDE ranged from 0.006 – 0.162mSv/y and ELCR 0.29 × 10⁻³ at most sampling points. Radon concentration did not decline monotonically with distance, VI- East reached its survey maximum at 500m, and elevated readings persisted 2km from the pit. This results showed that exposure is driven primarily by geogenic/structural control from basement lithology, with a secondary genuine anthropogenic amplification from fracture enhanced radon emanation near the mining disturbance. Relative to comparable Nigerian and West African NORM studies, the exposure recorded is real and exceeds international guidance but is intermediate in severity. These research findings support an area-based, rather than excavation confined, approach to radiological risk mitigation around artisanal mining sites.

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Introduction

Radon emanated from rocks, soil and minerals that are exposed through mineral exploration poses health threats and increases the natural background radiation level. Radon-222 is naturally occurring, colourless, odourless and chemically inert noble gas produced in the decay series of Uranium-238, arising directly from the radioactive decay of radium-226, which itself present in trace but variable analysis in virtually in all rocks and soils (Statpearls-Radon toxicity, NCBI Bookshelf: Cellular and Molecular carcinogenic effects of radiation exposure: A review, 2013). Because it is noble gas rather than a solid particulate, radon is uniquely mobile among the radioactive decay products found in soil. It can diffuse and be advectively transported through pore spaces, fractures, and joints in soil and rock, ultimately escaping to the atmosphere (soil-gas exhalation), dissolving into groundwater or migrating into the substructure and indoor air of buildings constructed on or near –bearing ground. The rate at which radon escapes from soil into the overlying environment its exhalation rate is controlled jointly by the radium-226 content of the parent materials and by soil physical properties, noble porosity, grain size, moisture content and permeability which together determine how readily the gas can migrate before it decays. Radon itself has a half-life of 3.82 days, long enough to allow substantial migration from depth to the surface, but it

own decay products polonium-218, lead-214, bismuth-214 have much more shorter half-lives and are solid, chemically reactive species that readily attach to air borne dust and aerosol particles once radon decays in air (Radon-the element of risk: the impact of radon exposure of human health, 2020). Radon gas is now widely recognized as the second leading cause of lung cancer worldwide after cigarette smoking and the cause among people who have never smoked, with a strong synergistic effect observed between radon exposures and tobacco smoke (ATSDR, clinician Brief on Radon, 2012). Beyond lung cancer, a recent systematic review and meta-analysis examined whether radon exposure is also linked to cardiovascular diseases neurodegenerative disease, and other nonmalignant outcomes; while none of the pooled association reached statistical significance, the authors concluded that such effects could not be ruled out and called for further well-designed studies . Because of this well-established carcinogenic risk, several international bodies have issued reference levels intended to guide national radon-management policy. The World Health Organization Handbook on indoor radon recommends that countries adopt a national reference level of 100 Bq/m³ for indoor radon and specifies that, where this cannot be achieved due to prevailing national circumstances, the chosen should not exceed 300 Bq/m³ a concentration corresponding to an annual effective dose of approximately 10mSv. The international commission on Radiological protection (ICRP), in publication 126, likewise recommends an upper reference level of 300 Bq/m³. For Radon in homes and workplace while encouraging national authorities

Sample Data Collection

A total of 25 soil samples were collected radially from three major pits in Vi, Shaffa and Garta sama communities of Michika LGA Adamawa State Nigeria. The positions of sampling points were taken using Global positioning system (GPS). Each sample was carefully tighten in a black polythene bag at the point of sampling and was coded before analysis with RAD-7 electronic detector at BUK. The samples codes followed: VE – S50m to VE - S2KM, VS – S 50m to VE – S2km, VW – S50m to VW- S2km, indicating the radial transect of Vi pit at 50m, 100m, 200m, 500m and 2km from the pit. GS –S50m to GS- S2km and S50 – S2km, for Shaffa and Garta sama respectively. 50m -100m are mining sites, 200m – 500m are farming sites and 2km the control zone. Soil samples were collected from each of the zone at 0 – 30cm depth.

Sample Analysis

Radon concentration from each zone was measured using RAD-7 electronic detector. This detector converts alpha radiation directly to an electrical signal and determines the energy of each alpha particle. In this research, the detector was connected to a kit containing the soil sample which enables it to remove radon gas from the soil sample into the air in a closed loop. Within the closed loop is a desiccant to dry the air before entering the detector for radon concentration measurement. Each sample was assayed for 30 minutes for each cycles, a total of 48 cycles were attained for each sample, this making 24hrs for a complete run in line with standard procedure.

Results and Discussion

The results for this research and its comparison with some related literatures and regulatory bodies are as follows:

Radiological Hazard Parameters

I. Dose Rate and Annual Effective Dose Equivalent, and radon concentration are reported. The Dose rate was obtained using the equation:

$$DR(nGy/h) = \frac{C_{RN} \times F \times DCF}{0.7} \quad 1$$

DR = Dose rate

0.7 = the conversion factor to convert the absorbed dose rate to annual effective dose equivalent

F = 0.4 Equilibrium

DCF = 9nSv/h per Bq/m³

II. Inhalation dose- Annual Effective Dose Equivalent

$$AEDE = C_{Rn} \times F \times T \times DCF \quad 2$$

C_{Rn} = Radon in the soil sample

T = 7000h/y

III. Excess lifetime Cancer Risk

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

RF = 0.05 Sv⁻¹

DL = 70yrs

Table 1: RADON-222 Concentration at 50m and 100m FROM PIT

Descriptive Statistics								
		Mean	Standard Deviation	Skewness	Kurtosis	Minimum	Median	Maximum
Sample ID	VE-Soil	1	--	--	--	1	1	1
	VW-Soil	2	--	--	--	2	2	2
	VS-Soil	3	--	--	--	3	3	3
	GS-Soil	4	--	--	--	4	4	4
	SS-Soil	5	--	--	--	5	5	5
Rn-222 at 50m	VE-Soil	5798	--	--	--	5798	5798	5798
	VW-Soil	2752	--	--	--	2752	2752	2752
	VS-Soil	3827	--	--	--	3827	3827	3827
	GS-Soil	267	--	--	--	267	267	267
	SS-Soil	1702	--	--	--	1702	1702	1702
Rn-222 at 100m	VE-Soil	5308	--	--	--	5308	5308	5308
	VW-Soil	2478	--	--	--	2478	2478	2478
	VS-Soil	2843	--	--	--	2843	2843	2843
	GS-Soil	257	--	--	--	257	257	257
	SS-Soil	1641	--	--	--	1641	1641	1641
Rn-222 at 200m	VE-Soil	5459	--	--	--	5459	5459	5459
	VW-Soil	3699	--	--	--	3699	3699	3699
	VS-Soil	3699	--	--	--	3699	3699	3699
	GS-Soil	313	--	--	--	313	313	313
	SS-Soil	1976	--	--	--	1976	1976	1976

Rn-222 at 500m	VE-Soil	6438	--	--	--	6438	6438	6438
	VW-Soil	2369	--	--	--	2369	2369	2369
	VS-Soil	2369	--	--	--	2369	2369	2369
	GS-Soil	391	--	--	--	391	391	391
	SS-Soil	1201	--	--	--	1201	1201	1201
Rn-222 at 2km	VE-Soil	4405	--	--	--	4405	4405	4405
	VW-Soil	2496	--	--	--	2496	2496	2496
	VS-Soil	2733	--	--	--	2733	2733	2733
	GS-Soil	267	--	--	--	267	267	267
	SS-Soil	1140	--	--	--	1140	1140	1140

The results obtained from the table above showed that none of the five soils collected from the sampling point decline monotonically with distance. VE-Soil at a distance of 500m, VW-soil and VS-soil both at 200m from the pit has an identical activity concentration, GS-soil activity concentrations rises steadily at a distance of 500m, while it concentration declined at 50m from the mining pit, at 2km, the activity concentration was less than for all the sampling locations, despite it was the control zone, the results clearly explained that the activity concentration does not depend on distance, because research showed that Rn-222 diffused at 10cm from the mining zone. Research showed that activity concentrations increase at a distance far away from the mining pit and decrease at a close distance . VE-soil’s ranged across the whole transect (4405-6438 Bq/m³) stays within the upper-normal soil-gas radon of 2,000 -50,000 Bq/m³ recorded by Huxtable et al (2017), while the activity concentration measured from the South of Garta sama pit range from 257 – 391Bq/m³, remains persistently low at every distance reinforcing the earlier point that GS-soil behaves as an intrinsically low-emanation substrate regardless of proximity to whatever source or distance axis represents, similar to the low, near-background values reported in the Al-Qassim arid-soil survey. The average mean and its percentage for all the activity concentrations across the five sampling locations are as follows: VE-Soil: 2,033Bq/m³ 35% of its mean. VS-Soil: 1,458 Bq/m³, 46% of its mean, VW: 1,330Bq/m³, 47% of its mean, SS-Soil: 836 Bq/m³ 52% of its mean, GS-Soil: 134Bq/m³ 44% of its mean. Proportionally, all five soils show comparable relative spatial variability (35 -52%), which is broadly in line with the field-scale spatial coefficients of variation reported for soil radon 26% at shallow depth in one porous test field (Winkler et al.,2001), and coefficient of variation values of 24-80% across boreholes in an active zone.

Table 2: Sample Locations with Dr (nGy/y), AEDE (mSv/Y) AND ELCR

Descriptive Statistics										
	Mean	Standard Deviation	SE of mean	Lower 95% CI of Mean	Upper 95% CI of Mean	Sum	Skewness	Minimum	Median	Maximum
Sample ID	17	22.0794	1.22474	14.47225	19.52775	5525	-0.04922	1	18	25
DR	1.43424E-5	2.85902E-5	1.5859E-6	1.10692E-5	1.76155E-5	0.00466	0.63484	1.32E-6	1.37E-5	3.31E-5
AEDE	0.05553	0.16705	0.00927	0.03641	0.07466	18.0475	0.76616	0.0043	0.05	0.162
ELCR	0.1964	0.57957	0.03215	0.13005	0.26275	63.829	0.75898	0.021	0.17	0.567

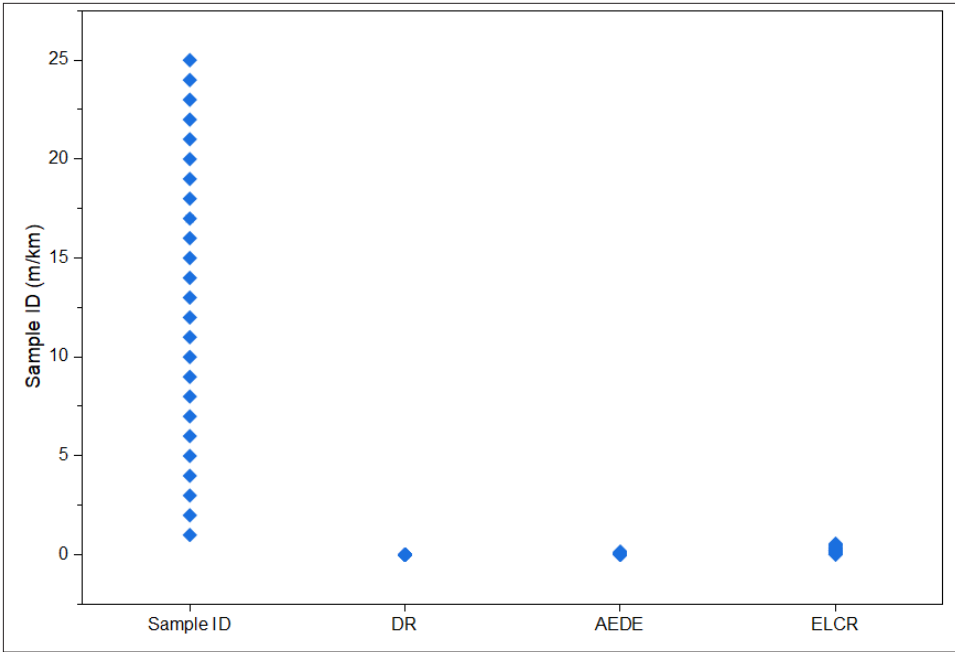


Figure 3: Box Plot of Samples, DR, AEDE and ELCR.

Dose Rate (DR)

As tabulated, dose rate (DR) ranges from 1.32×10^{-6} – 3.31×10^{-5} (mean 1.43×10^{-5} , median 1.37×10^{-5} , SD 2.86×10^{-5}). The tight clustering of mean and median relative to the wide confidence interval is consistent with the moderate positive skew (0.635) reported. AEDE derived estimate of the conventional absorbed dose rate calculated using standard UNSCEAR relation: Mean implied DR = 45.3nGy/h (range = 3.5 -132nGy/h, median =40.8nGy/h). This implied mean sits below the UNSCEAR (2000) world population weighted average of 59nGy/h, though the upper end of the range exceeds it, indicating at least one or few elevated sampling locations.

Annual Effective Dose Equivalent (AEDE)

AEDE ranges from 0.0043 to 0.162 mSv/y. Every reported value, including the maximum, is below the ICRP publication 103 public dose constraint of 1mSv/y above background, and the mean is below the UNSCEAR outdoor world average of 0.07 mSv/y, although several of the higher end samples approach or modestly exceed that world average, again reflecting the right-skewed distribution.

Excess Lifetime Cancer Risk (ELCR)

ELCR ranges from 0.021 to 0.567. The UNSCEAR/ICRP derived world average reference value of 0.29×10^{-3} falls inside the observed range but above the sample mean and median, meaning that on average the sampled soils confer a modelled excess lifetime cancer risk below the global reference value, while the single highest-risk location(s) in the data set exceed it by a factor of two.

Box-Style Figure

The sample ID spans 1-25 in unit steps, confirming N= 25. The DR, AEDE and ELCR are compressed near the base of the plot because their absolute magnitudes are orders of magnitude smaller than the sample ID axis range, plotting them on a shared linear axis with sample ID obscures their internal spread.

Comparison with International Regulatory Guidance

On a mean basis, the sampled soils fall below the UNSCEAR world averages for absorbed dose rate, AEDE and ELCR, are well below the ICRP public dose constraint. On a maximum basis, AEDE and DR remain below their respective world averages/constraints, while the maximum ELCR is roughly double the UNSCEAR/ICRP reference value of 0.29×10^{-3} , a pattern that mirrors several of the benchmark studies below, where means sit near or below world averages while a minority of individual sampling points exceed them. This is consistent with UNSCEAR own framing of its reference values as population weighted averages, not upper safety limits, and with ICRP system of dose constraints, which are designed to flag individual sources or locations warranting closer scrutiny rather than to certify an entire site as hazardous from a mean value alone.

Comparison with Recent Peer-Reviewed Literature

Kucukonder, Gumbur, Sgut and Dogru(2023) measured U-238, Th-232, and K-40 together with gross alpha/beta activity in soils from kahramanmaras, Turkiye, reporting a mean terrestrial absorbed gamma dose rate of 9.81 nGy/h well below the UNSCEAR world average with correspondingly very low AEDE and ELCR, and concluded that the acquired data were consistent with both domestic and international safety standards.

Kanmi, Ibrahim, Goki, Sayyed, Maghrbi, Namq, Najam and Wais(2025) surveyed 24 soil samples across six local government

areas of Kwara State, Nigeria, quantifying U-238, Th-232 and K-40 by NaI(TL) scintillation detector and deriving the standard radiological hazard indices; this study forms part of a wider West African body of work in which soils in undisturbed or lightly used land are typically reported within UNSCEAR/ICRP reference levels, while soils overlying active mineral workings are more often reported above them.

Namq and Wails (2026) assessed 50 soil samples from the North oil company area of Kirkuk, Iraq, reporting a mean absorbed dose rate of 39.21nGy/h, mean AEDE of 48.09 μ Sv/y, and a Monte-Carlo simulated mean ELCR of 1.88×10^{-6} slightly above the UNSCEAR reference

Of 0.29×10^{-3} used in that papers own units, but the authors characterized the overall radiological risk to the local population as low, while noting spatially localized hotspots linked to oil-extraction activity that warrant continued monitoring.

AL-Sudani, Sherif and Mohammed (2025) measured Ra-226, Th-232 and K-40 in 47 soil samples from Ali Al-Shariq and Kumait, Misan province, Iraq, using a high-purity germanium detector, reporting total absorbed dose rates of 68.3 and 72.0 nGy/h, total AEDE of 0.2 and 0.3 mSv/y and total ELCR of 0.9×10^{-3} at both sites all below UNSCEAR world averages and concluded the soils posed no health risk to the public while providing useful baseline data for future radiological monitoring.

Namq et al (2025) evaluated radiological risks from natural radionuclides in the soil of Khanaqin district, Diyala, Iraq, computing the same suit of hazard indices using methodology that is directly cited and reused in the 2026 kirkuk study above, reflecting a coherent and actively maintained Iraqi soil radioactivity monitoring programme.

Conclusion and Recommendation

The soil radiological data set summarized here shows mean Dose rate, Annual Effective Dose Equivalent and Excess Lifetime Cancer Risk values that are broadly at below UNSCEAR (2000) world population –weighted averages and below the ICRP publication 103 (2007) public dose constraint, consistent with several recent peer-reviewed soil survey reviewed in the report. The data are right; skewed with number of elevated samples, and the highest risk sample exceeds the UNSCEAR/CRP ELCR reference value by a factor of roughly two – a pattern that, in comparable published studies, typically being traced to specific geological industrial source once location data are examined.

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