VOL. 10 NO. 9,
NOVEMBER, 2025
E-ISSN 3026-958X
P-ISSN 3027-1169

African Scholar Publications & Research International
www.africanscholarpub.com

Journal of Science Innovation & Technology Research (JSITR)

Estimation of Linear No-Threshold (LNT) Cancer Risks from Radon Concentrations in Groundwater Samples from Mubi-North Metropolis, Adamawa State, Nigeria

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DOI: https://doi.org/10.70382/ajsitr.v10i9.057

Abstract

This research assessed the Radon (^{222}Rn) concentrations in groundwater sources from Mubinorth metropolis, and estimated the associated excess lifetime cancer risk (ELCR) using the linear no-threshold (LNT) model. Radon concentration was estimated from the gross alpha activity concentration obtained using MCP 2000-DP at center for energy research and training (CERT) Ahmadu Bello University, Zaria. The mean Radon activity concentration in water and air ranging from 0.0082 – 0.1518 and 3.28 $x10^{-9}$ -6.072 $x10^{-8}$ Bq/L respectively, this meant that the concentration of Radon in water is far greater than in air, the annual effective dose for the locations ranging from 9.44 $x10^{-18}$ – 4.723 x 10^{-16} Sv, and the excess lifetime cancer risk (ELCR) ranging from 3.637 x 10^{-17} – 1.818 x 10^{-15}. The concentration of Randon in all the sampling locations were below the recommended screening limit of 0.5Bq/L by world health organization (WHO) and other radiation protection agencies, therefore the water from the locations is good for drinking and domestic activities.

Keywords: Radon, water quality, Linear no- threshold, cancer risk, Groundwater, Concentration, Health risk, Mubi−North.

Introduction

Radon-222 (Rn-222) is a naturally occurring radioactive gas that originates from the decay of uranium and thorium in the Earth's crust. When released into groundwater, it can dissolve and later escape into indoor air, where it presents a health hazard through both inhalation and ingestion (USEPA, 2023). Elevated exposure to radon has been strongly correlated with a higher risk of lung cancer, making it one of the most significant sources of natural radiation to humans. According to the linear no-threshold (LNT) model, even the smallest dose of ionizing radiation carries a measurable risk of inducing cancer (WHO, 2023).

Although groundwater serves as a major source of drinking water in many regions, routine monitoring for radon contamination remains inadequate. Dissolved radionuclides in water emit alpha and beta particles, as well as gamma photons, all of which contribute cumulatively to radiation exposure in biological tissues. Findings from experimental and epidemiological studies involving humans and animals suggest that exposure to low and moderate levels of ionizing radiation can elevate the long-term probability of developing cancer (Farai et al., 2023).

Radon exists in three naturally occurring isotopic forms: radon-222, thoron (radon-220), and actinon (radon-219), with half-lives of approximately 3.8 days, 55.8 seconds, and 3.98 seconds, respectively (Abdullahi et al., 2021). These isotopes are produced during the radioactive decay chains of uranium-238, uranium-234, and thorium-232, which are commonly found in minerals, rocks, soil, and the atmosphere (Abdullahi et al., 2020). Specifically, radon-220 arises from the alpha decay of radium-224 in the thorium-232 series, while radon-222 is part of the uranium-238 decay series. Radon-222 is particularly important because it is the most stable and abundant isotope, which is why the term “radon” typically refers exclusively to this isotope in environmental studies (Dankawu et al., 2021).

Due to its instability, radon-222 further decays into a series of short-lived radioactive progeny, including polonium-218, lead-214, bismuth-214, and polonium-214 (Belete & Anteneh, 2021). These decay products attach to airborne particles and, when inhaled, can deposit in the respiratory tract, irradiating lung tissues. The primary source of radon is soil and rock underlying buildings. The gas seeps into structures through cracks in floors, gaps around pipes, and porous construction materials such as bricks, concrete, and plaster (WHO, 2023). Moreover, radon can dissolve in groundwater and enter domestic water supplies, where it may later diffuse into indoor air during activities such as showering or cooking (USEPA, 2003).

MATERIALS

The gas-flow proportional counting system (MPC 2000-DP) is a low-background detector designed to measure alpha and beta radiation on prepared planchets, providing sensitive quantification of radionuclide activity in environmental samples. Planchets serve as shallow sample holders on which dried residues of water samples are deposited, ensuring a uniform geometry and reproducible counting conditions. An electric hot plate and drying oven are used

sequentially to evaporate water and dry the residues at controlled temperatures, improving adhesion of the sample to the planchet and minimizing moisture that could affect counting efficiency or background.

Standard laboratory glassware (such as beakers, measuring cylinders, and funnels) is used for sampling, measuring volumes, and transferring solutions during pre-treatment and chemical conditioning of the water. An analytical digital balance provides precise mass measurements of solids or evaporated residues, which are necessary for calculating activity concentrations on a mass or volume basis. A spatula is employed to handle solid reagents and transfer small quantities accurately, reducing contamination and ensuring reproducible sample preparation.

REAGENTS

Vinyl acetate likely functions as a film-forming or binding agent to stabilize the dried residue on the planchet surface, improving mechanical integrity and counting reproducibility. Nitric acid is used to acidify samples, dissolve metal ions and radionuclides, and adjust chemical conditions to keep radionuclides in solution during pre-concentration or before evaporation; it can also help clean glassware and planchets by removing trace contaminants. Acetone acts as an organic solvent and drying aid, promoting rapid evaporation, degreasing planchets, and assisting in the formation of a uniform thin layer of sample and binder on the planchet surface, which is critical for efficient alpha/beta detection.

STUDY AREA

The study is conducted in Mubi-North Metropolis, a locality where groundwater and reservoir water represent important drinking and domestic water sources. The sampling design covers five specific locations: the Federal Polytechnic Mubi reservoir, Adamawa State University Faculty of Management Science borehole, Lokuwa borehole, Shagari Locust borehole, and Wuro Gude borehole, allowing comparison of radionuclide levels across institutional and community water supplies within the same metropolitan area. This spatial coverage supports assessment of potential variability in natural radioactivity due to geological differences, construction of boreholes, and local hydrogeological conditions that may influence radon and radionuclide content in water.

SAMPLING STRATEGY

A convenience (non-probability) sampling approach was adopted, targeting wells and boreholes that are in regular use for drinking and domestic purposes within Mubi-North Metropolis. Convenience sampling selects sites based on accessibility and frequent use, which is suitable for preliminary environmental health assessments but does not allow formal statistical generalization to all wells in the area. To improve representativeness, an

initial field survey was conducted to identify existing wells and boreholes and to document those most frequently used by local residents.

All sampling sites were geo-referenced using a handheld Global Positioning System (GPS) receiver, and coordinates were recorded for mapping and future repeat sampling. Sampling was carried out under favorable, dry weather conditions to minimize short-term dilution or contamination effects associated with rainfall events and surface runoff.

SAMPLE COLLECTION PROCEDURE

Water samples were collected in pre-cleaned, high-density polyethylene (HDPE) containers with a nominal capacity of 2 L. Before sampling, each container was rinsed three times with the water from the specific well or borehole to minimize contamination from any residual material within the container. This triplicate rinse step helps condition the container surface to the sample matrix and is standard practice in water sampling protocols.

Each sample was collected to approximately 99% of the container volume, leaving about 1% headspace to accommodate thermal expansion and prevent leakage or container deformation during transport and storage. Immediately after collection, 1 mL of concentrated nitric acid (analytical grade) was added to each 2 L sample to reduce the pH to below 2. Acidification stabilizes dissolved metals and radionuclides by minimizing precipitation and adsorption onto container walls, thereby preserving the original concentration until analysis. The containers were then tightly capped, clearly labelled with sample ID, location, date, and time of collection, and transported to the laboratory, where they were stored at room temperature in the dark until analysis.

SAMPLE EVAPORATION AND RESIDUE PREPARATION

For each water sample, an aliquot of up to 2 L was transferred into a 500 mL borosilicate glass beaker and evaporated on a temperature-controlled hot plate without stirring, under a fume hood, until near dryness. Because of the large initial volume and low total dissolved solids, complete evaporation of 2 L typically required about 2.5 days. The remaining residue was then rinsed with a small volume of distilled water to collect all solids and quantitatively transferred into a 7.1 cm^2 stainless-steel or aluminium counting planchet.

The planchet containing the residue was dried in a thermostatically controlled drying oven at 105 °C for 2 hours to remove residual moisture and to ensure a stable, adherent film suitable for alpha/beta counting. After drying, the planchet was cooled in a desiccator to room temperature to prevent moisture uptake, then weighed using an analytical balance and subsequently counted. When immediate counting was not possible, prepared planchets were stored in a desiccator to maintain constant mass and prevent contamination.

The content of the beaker is then transferred to a planchet and the weight of the beaker was taken again, $W_{B\text{-}S}$. The difference between $W_{B\text{-}S}$ and W_B gives the total weight of sample unrecovered from the beaker.

$$Sampling\ Efficiency = \frac{(W_{B+S} - W_B) - (W_{B-S} - W_B)}{W_{B+S} - W_B} \times 100\% \quad (1)$$

The Radon concentration activity is calculated using the relationship:

$$A_{Rn} = \frac{A_{g\alpha} \times F_{Rn}}{E_{Rn}} \quad (2)$$

RADON ACTIVITY CONCENTRATION

The radon (or radon progeny) activity concentration in water is then determined from the net count rate obtained with the gas-flow proportional counter, corrected for background, counting efficiency, sample mass or volume, decay (if applicable), and the preparation efficiency defined above. In your thesis or article, the explicit formula should be given in terms of these parameters (net counts, counting time, detector efficiency, volume or mass of water, and clearly referenced to relevant standards or guidance documents (e.g., WHO drinking-water guidelines or IAEA measurement protocols).

METHODOLOGY

Water samples (500 mL) were placed in clean beakers and gradually evaporated on a temperature-controlled hot plate over several days, as slow evaporation minimizes loss of volatile radionuclides and prevents splattering or sample loss. Once the sample volume reduced to less than 100 mL, the concentrate was carefully transferred to a petri dish and evaporated to dryness to ensure efficient collection of all suspended and dissolved solids. The final dried residue was gently scraped and transferred into accurately weighed stainless steel counting planchets. Achieving a residue mass of 0.77 g provided sufficient material for reproducible counting, especially for low-activity samples.

ALPHA RADIOACTIVITY MEASUREMENT

The dried residues were measured for alpha radioactivity with the MPC 2000-DP proportional counter, a widely used gas-filled detector offering suitable sensitivity and low background for environmental radioactivity. The proportional counter operates with a fill gas (typically a mixture like P-10, 90% argon and 10% methane), allowing discrimination of alpha from beta events, and achieving very low background counts crucial for trace level analysis, as required by international guidelines. The count rates observed were reproducible both across measurement channels and in repeat measurements, confirming stable sample preparation and instrument reliability.

DETECTOR SELECTION AND RATIONALIZATION

While proportional counters (such as the MPC 2000-DP) are standard for low-level alpha and beta measurements, alternative detectors like High Purity Germanium (HPGe) and Sodium Iodide (NaI) are available. HPGe detectors, though superior for gamma spectrometry due to their high energy resolution, are less commonly used for gross alpha/beta measurement in water due to their complexity and cost. Sodium Iodide detectors

are effective for highsensitivity gamma counting but lack discrimination for alpha and beta particles. The MPC 2000-DP system was chosen for its accessibility and the nearly uniform low background levels it provides, ensuring reliable detection at low activity concentrations.

RESULTS AND DISCUSSION

TABLE 1 C_w (Bq/L), C_a (Bq/L), D_{eff} (Sv), ELCR from water sample.

S/N	SAMPLE ID	C_w (Bq/L)	C_a (Bq/L)	D_{eff} (Sv)	ELCR
1	A	0.0554	$2.216X\ 10^{-8}$	$6.382\ X10^{-17}$	$2.457\ X10^{-16}$
2	B	0.0082	$3.28\ X\ 10^{-9}$	$9.446\ X10^{-18}$	$3.637\ X10^{-17}$
3	C	0.0492	$1.968\ X10^{-8}$	$5.668\ X10^{-17}$	$2.182\ X10^{-16}$
4	D	0.1518	$6.072\ X\ 10^{-8}$	$1.749\ X\ 10^{-16}$	$6.34\ X10^{-16}$
5	E	0.0410	$1.64\ X10^{-8}$	$4.723\ X10^{-16}$	$1.818\ X\ 10^{-15}$

From the table above sample D has the highest measured radon concentration in water (0.1518 Bq/L) and highest risk estimates, but still remains below health and safety guideline levels for drinking water.

All annual effective dose values remain many orders of magnitude below international dose limits, implying no significant radiological risk from waterborne radon for residents using these sources.

Excess lifetime cancer risks reported in this study are extremely small, much less than the thresholds commonly used by regulatory authorities.

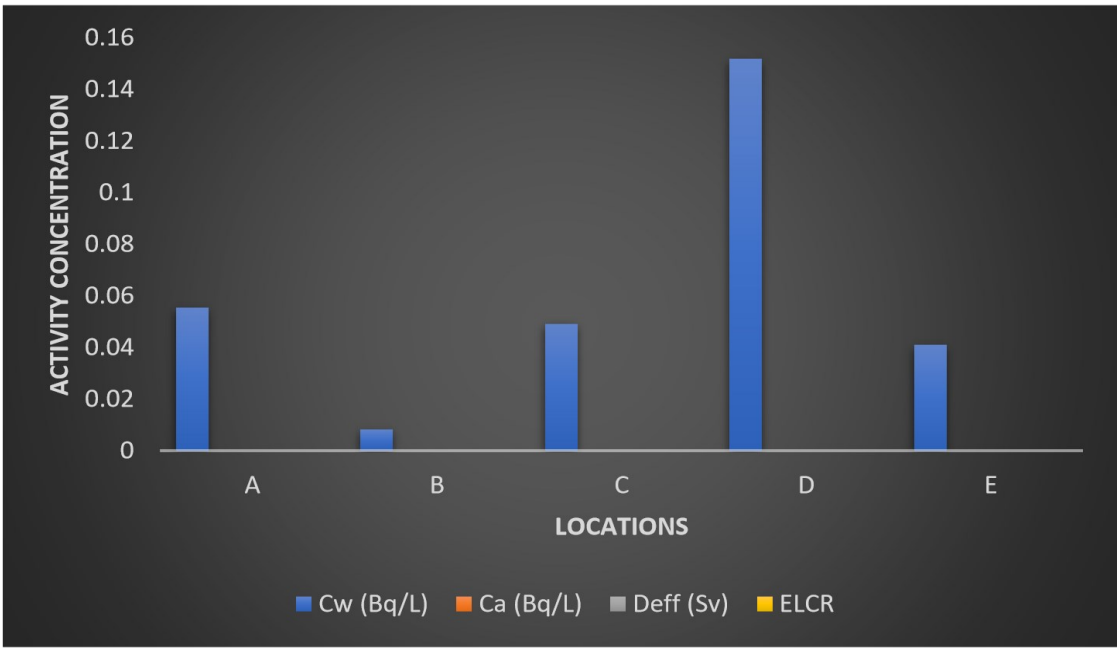


Figure 1 The chart showing Activity concentrations.

This chart displays the values for radon in water (Cw), air (Ca), annual effective dose (Deff), and excess lifetime cancer risk (ELCR) at different locations. A detailed discussion of the correlation involves analyzing how these metrics behave relative to one another across the samples. Cw (radon in water) has much higher values compared to Ca, Deff, and ELCR at all locations. This visually confirms that the concentration of radon in water is the primary driver behind other risk metrics, such as effective dose and cancer risk.

Locations with higher Cw also indicate higher Ca, Deff, and ELCR—for example, location D shows a peak in water radon and would likewise have the highest associated air concentration, dose, and risk if their scales were visible. This pattern reveals a direct, positive correlation: as waterborne radon concentration rises, so too does the risk for exposure and its health impact. Even the highest Cw, at location D, results in very small values for Ca, Deff, and ELCR, showing that even where radon is relatively abundant in water, the consequential risks remain low when compared to international safety standards. This suggests a diminishing return in risk increase beyond a certain radon threshold in water.

The chart's structure allows for direct comparison between samples. Locations B and E, with the lowest Cw values, naturally have the lowest likely values in the other metrics, confirming the consistent interdependence between radon presence and risk.

One critical observation is that the selected axis scale makes only Cw visually prominent, and Ca, Deff, and ELCR bars are nearly invisible. This means that the absolute values of risk are not only lower, but their change between locations is proportionally less than the change seen for Cw. The positive correlation between Cw and derived metrics (Ca, Deff, ELCR) is expected, as most risk assessment formulas for radon are based on waterborne concentrations. The risk increases linearly with radon concentration in water, but remains low if absolute concentrations are small.

TABLE 2 DIFFERENCE BETWEEN RADON IN WATER (C_w) AND AIR (C_a)

S/N	SAMPLE ID	(C_w) Bq/L	(C_w) Bq/L
1	A	0.0554	$2.216X\ 10^{-8}$
2	B	0.0082	$3.28\ X\ 10^{-9}$
3	C	0.0492	$1.968\ X10^{-8}$
4	D	0.1518	$6.072\ X\ 10^{-8}$
5	E	0.0410	$1.64\ X10^{-8}$

The table above show that; Radon concentration in water (Cw) and air (Ca) are closely linked due to the process whereby radon dissolved in water can be released into air during water use. However, the absolute values and their impact differ greatly, as reflected in the data.

Cw (Bq/L): This represents the concentration of radon present in the water samples. Values range from 0.0082 to 0.1518 Bq/L in the table, well below regulatory concern levels for drinking water (WHO intervention level is 100 Bq/L; EPA limit is 11.1 Bq/L).

Ca (Bq/L): Radon in air due to water use is several orders of magnitude lower, ranging here from about 3.28×10^{-9} up to 6.072×10^{-8} Bq/L. This is because only a small fraction of the radon dissolved in water is released into the air and it is greatly diluted by the much larger volume of air in typical living spaces.

The amount of radon potentially released into indoor air from water increases linearly with the radon content of that water (Cw and Ca show direct proportionality in the data).

CONCLUSION

All water samples tested exhibited radon concentrations far below both the local screening level of 0.5 Bq/L and international standards, such as the US EPA's proposed regulatory limit of 11.1 Bq/L, with typical action levels by WHO and other organizations ranging from 10 to 100 Bq/L. These results indicate that there is no significant health risk from radon exposure via drinking water in the tested locations at this time. The levels of radon detected are orders of magnitude lower than those associated with a measurable risk for cancer or other radiationinduced health effects according to global risk models. This means residents using these water sources are not at increased risk for radon-related conditions. The study confirms that all sampled water sources meet or surpass international standards for potable water safety with respect to radon content. There is no regulatory requirement for remediation or special treatment at these concentrations.Despite the reassuring results, radon concentrations in natural and groundwater sources can fluctuate due to geological, hydrological, or seasonal changes. Regular and systematic monitoring remains essential to detect any future rise in radon levels, maintain public health vigilance, and ensure rapid response if concentrations ever approach regulatory thresholds.

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