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Assessment of Gross Alpha Radioactivity and Derived ^{222}Rn Activity Concentrations in Groundwater Sources in Mubi-North Metropolis, Adamawa State, Nigeria

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ABSTRACT
Groundwater abstracted from boreholes serves as the primary drinking water supply for many communities in Mubi-North Metropolis, Adamawa State, Nigeria, yet the radiological quality of these sources has received little systematic attention. This study quantified gross alpha radioactivity and derived radon (^{222}Rn) activity concentrations in water samples drawn from five boreholes distributed across the metropolis. Samples were processed by evaporative concentration and the resulting residues were counted using a gas-flow proportional counting system (MPC 2000-DP) at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. Radon activity was subsequently calculated from gross alpha measurements in units of Becquerels per litre (Bq/L). Recorded radon values ranged from 0.0082 Bq/L at Site B (Adamawa State University) to 0.1518 Bq/L at Site D (Lokuwa Community Borehole). Every site returned a concentration well beneath the 0.5 Bq/L screening guideline prescribed by the World Health Organization and allied radiation protection authorities, confirming that the examined groundwater sources are radiologically acceptable for potable and domestic application under present conditions.

Keywords:
Radon,
Gross Alpha Radioactivity,
Groundwater,
Radon screening,
Mubi-North,
Nigeria

INTRODUCTION

Waterborne radionuclides represent a growing concern in environmental health, owing to the direct internal exposure pathway they create upon ingestion. Once taken into the body, dissolved radioactive species continuously irradiate surrounding biological tissue through the emission of alpha and beta particles and gamma radiation. The association between cumulative radiation exposure and an elevated probability of malignant disease has been documented in the epidemiological and experimental literature (Farai et al., 2023; WHO, 2023; USEPA, 2003). Radon (^{222}Rn), a chemically inert noble gas produced by the radioactive decay of radium-226 in the ^{238}U decay chain, is among the most radiologically significant dissolved species in groundwater due to its alpha-emitting progeny and its volatility upon release from water to air (Appleton, 2013; Kendall & Smith, 2002).

Geogenic sources drive the entry of radon into both indoor air and water supplies. The gas is continuously generated within uranium- and thorium-rich rocks and soils, from which it migrates into the atmosphere and infiltrates-built structures via foundation gaps and permeable building fabric (WHO, 2023). Subsurface water in contact with radon-bearing geological formations dissolves the gas and transports it to the surface through extraction boreholes or springs, making groundwater a key ingestion exposure route — particularly in geological terrains with elevated natural radioactivity (USEPA, 2003). Because direct radon-specific measurement techniques such as liquid scintillation counting require specialised equipment that is not universally available, gross alpha radioactivity screening is widely employed as a practical first-tier indicator of potential radon contamination; the method measures total alpha-emitting activity and uses a conversion factor to estimate dissolved radon, with the acknowledged limitation that volatile radon is partially or fully driven off during sample evaporation so that the residual activity reflects non-volatile alpha emitters (principally uranium, radium, and polonium isotopes) rather than radon itself (USEPA, 2003; Appleton, 2013).

Mubi-North Metropolis, located in Adamawa State, northeastern Nigeria, draws its principal potable water supply from groundwater abstracted through boreholes. Despite heavy community reliance on these sources, published data on their radiological character remain sparse. The present investigation was therefore undertaken to quantify gross alpha radioactivity and derive radon activity concentrations in five representative borehole water sources across the metropolis, and to benchmark those values against the safety thresholds stipulated by the World Health Organization and the United States Environmental Protection Agency.

MATERIALS AND METHODS

Study Area

Fieldwork was carried out in Mubi-North Metropolis, situated in Adamawa State, northeastern Nigeria. The area is characterised by a semi-arid climate and depends heavily on groundwater abstraction to meet domestic and institutional water demand. Five borehole water sources, each actively used by the surrounding community for potable and household purposes, were identified for inclusion in the study (Table 1). Precise geographic coordinates for each borehole were recorded in the field with a Global Positioning System (GPS) receiver to enable spatial referencing of results.

Sample Collection

A purposive convenience sampling strategy was employed, targeting boreholes representative of the diverse institutional, residential, and peri-urban contexts within the metropolis. Before each collection, the storage container was triple-rinsed with the source water to eliminate residual contamination from its prior contents. Two-litre aliquots were transferred into pre-cleaned high-density polyethylene (HDPE) bottles; a headspace of approximately 1% of container volume was deliberately maintained to accommodate thermal expansion during storage and transit. To suppress radionuclide precipitation and adsorption onto container surfaces, 1 mL of concentrated nitric acid (HNO_3) was immediately introduced into each sample post-collection, lowering the pH to below 2. All containers were securely capped, labelled with unique identifiers, and transported to the laboratory under ambient temperature conditions for subsequent processing.

Instrumentation and Reagents

Radioactivity measurements were performed on a gas-flow proportional counting system (MPC 2000-DP) housed at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. The instrument was selected for its well-characterised, near-uniform low-background response to low-level alpha emitters. Ancillary equipment included circular stainless steel planchets with an active deposition area of 7.1 cm², an electric hot plate for evaporative concentration, a thermostatically controlled drying oven, a calibrated analytical balance, standard laboratory glassware, and a desiccator for moisture-free storage of prepared samples. Chemical reagents employed during sample preparation were vinyl acetate, concentrated nitric acid, and acetone.

Sample Preparation and Analysis

An aliquot of 500 mL from each acidified water sample was transferred to an open 500 mL borosilicate beaker and concentrated by slow evaporation on the hot plate without mechanical agitation, a process requiring approximately two and a half days per two-litre sample. When the remaining liquid volume fell below 100 mL, the concentrate was decanted into a petri dish for final drying to a solid residue. The dried material was then carefully scraped and quantitatively transferred to a tared stainless steel planchet. A dry residue yield of approximately 0.77 g was obtained per sample. The planchet was then inserted into the MPC 2000-DP counting chamber for gross alpha radioactivity determination.

Gravimetric accounting was used to establish sample preparation efficiency. The mass of the empty beaker (W_B), the combined mass of beaker and dried residue prior to transfer (W_B+S), and the residual beaker mass following transfer (W_B−S) were each recorded individually. The difference W_B+S − W_B yielded the total residue mass, while W_B−S − W_B quantified the fraction that adhered to the beaker wall and could not be recovered, thereby providing a correction factor for efficiency calculations.

Calculation of Radon Activity Concentration

Radon activity concentrations were derived analytically from the experimentally measured gross alpha values by applying the relationship prescribed by the USEPA (2003):

$A_{Rn} = (A_{g\alpha} \times F_{Rn}) / E_{Rn}$ …(1) (USEPA, 2003)

where A_{Rn} is the derived radon activity concentration (Bq/L); $A_{g\alpha}$ is the measured gross alpha activity concentration (Bq/L); F_{Rn} is the fraction of gross alpha activity attributable to radon and its short-lived progeny (dimensionless; adopted value 0.833 per USEPA, 2003); and E_{Rn} is the counting efficiency of the MPC 2000-DP detector for radon alpha emissions (dimensionless; instrument-specific value 1.0 under the gravimetric efficiency correction applied in this study). It is noted that because samples were processed by hot-plate evaporation, the volatile fraction of dissolved radon will have been substantially driven off prior to counting; accordingly, the measured gross alpha activity and the derived radon values reported here represent contributions principally from non-volatile alpha emitters (uranium, radium, and polonium isotopes) co-present in the groundwater matrix, and the radon concentrations should be interpreted as screening estimates rather than direct measurements (USEPA, 2003; Appleton, 2013).

RESULTS AND DISCUSSION

Sampling Location Summary

Table 1: Description of groundwater sampling locations, Mubi-North Metropolis

Site ID	Location Description	Notes
A	Federal Polytechnic Mubi — Reservoir Borehole	Institutional water supply
B	Adamawa State University Borehole	Institutional water supply
C	Faculty of Management Sciences Borehole	Institutional/community water supply
D	Lokuwa Community Borehole	Community drinking water source
E	Shagari Locust / Wuro Gude Borehole	Peri-urban water supply

Gross Alpha and Radon Activity Concentrations

Gross alpha radioactivity and the corresponding derived radon activity concentrations for all five borehole sites are tabulated in Table 2. Across the sampled boreholes, gross alpha values spanned a range of 0.0098 to 0.1821 Bq/L, while the associated radon concentrations fell between 0.0082 and 0.1518 Bq/L. The Lokuwa Community Borehole (Site D) returned the maximum readings for both parameters, whereas the Adamawa State University borehole (Site B) yielded the minimum values in both categories. A consistent proportional relationship between gross alpha activity and derived radon concentration was observed across all five sites, reflecting the physical basis of the computational approach.

Table 2: Gross Alpha and Radon Activity Concentrations (Bq/L) Measured at Each Sampling Location, With WHO Screening Limit Shown for Reference

S/N	Site ID	Gross Alpha Activity (Bq/L)	Radon Activity (Bq/L)
1	A	0.0665	0.0554
2	B	0.0098	0.0082
3	C	0.0591	0.0492
4	D	0.1821	0.1518
5	E	0.0492	0.0410
—	WHO Limit	0.5	0.5

Discussion

Pronounced inter-site variation in both gross alpha radioactivity and derived radon concentrations was recorded across the five borehole sources, pointing to the influence of localised hydrogeological conditions on radionuclide loading in Mubi-North groundwater. Site D (Lokuwa) exhibited the highest gross alpha reading of 0.1821 Bq/L, translating into a radon activity of 0.1518 Bq/L — a value that accounted for roughly half of the total radon measured across all sites combined. The enrichment observed at this location is attributable to the well-documented mechanistic link between gross alpha emitters and radon production; aquifer rock matrices with elevated uranium or radium mineral content release radon continuously into pore waters, and Site D appears to overlie a comparatively radionuclide-rich geological formation (Abdullahi et al., 2020). Contributory hydrogeological factors may include prolonged groundwater residence time within mineralised fractures, restricted aquifer recharge that limits dilution, and the texture and permeability of the host rock.

Site B (Adamawa State University), by contrast, registered the lowest gross alpha activity (0.0098 Bq/L) and the lowest radon level (0.0082 Bq/L) — equivalent to roughly one-eighth of the Site D radon value and only approximately 2% of the WHO guidance threshold. Several factors could account for this markedly lower radiological signature: a shallower or more rapidly recharged aquifer supplying fresher water with reduced contact time with uranium-bearing minerals, greater dilution through higher-flow conditions, or the absence of radionuclide-enriched lithology directly underlying that abstraction point (Dankawu et al., 2021). Detailed geological mapping and hydrogeochemical profiling in future work would help resolve the precise drivers.

From a regulatory standpoint, the most important finding of this study is that none of the five sampled sites exceeded the WHO gross-alpha screening level of 0.5 Bq/L (WHO, 2023). It should be noted that this 0.5 Bq/L threshold applies specifically to gross alpha radioactivity as a first-tier screening parameter; the WHO Guidelines for Drinking-Water Quality (4th edition and addenda) do not prescribe a standalone numerical guideline value for dissolved radon in drinking water, addressing radon qualitatively under the indoor-air inhalation pathway (WHO, 2023). Even Site D, the highest-activity location, reached only 0.1821 Bq/L for gross alpha — representing approximately 36% of the WHO gross-alpha benchmark — while all remaining sites fell at or below 12% of that threshold. Regarding United States regulatory guidance, the USEPA proposed two radon limits for public water systems: a Maximum Contaminant Level (MCL) of 300 pCi/L (approximately 11.1 Bq/L) and an alternative MCL of 4,000 pCi/L (approximately 148 Bq/L) for states implementing multimedia mitigation programmes for indoor air (USEPA, 2003). All five sites in this study returned gross alpha values far below either proposed USEPA threshold. These findings are broadly concordant with published radiological surveys of groundwater across other Nigerian states, where analogous studies in Kano (Abdullahi et al., 2020), Jigawa (Dankawu et al., 2021), and Ogun (Farai et al., 2023) similarly reported radioactivity levels beneath internationally prescribed limits, suggesting that shallow basement aquifers in Nigerian sedimentary and metamorphic terrains generally exhibit moderate to low inherent radioactivity.

Regarding the analytical approach, the MPC 2000-DP gas-flow proportional counter was the instrument of choice for this study on account of its well-characterised, reproducible low background and its established suitability for gross alpha quantification in environmental water matrices. While gamma spectrometric systems such as High-Purity Germanium detectors offer isotope-specific resolution, the proportional counter platform is widely validated for the screening-level assessments required here. Deployment of complementary detection technologies in follow-up investigations would strengthen confidence in the reported values and permit direct isotope attribution.

CONCLUSION

Radiological characterisation of five community borehole water sources in Mubi-North Metropolis, Adamawa State, Nigeria was conducted through measurement of gross alpha radioactivity using a gas-flow proportional counting system (MPC 2000-DP), with estimated radon activity concentrations subsequently derived from those measurements using the USEPA (2003) conversion approach. The resulting gross alpha values ranged from a minimum of 0.0098 Bq/L at Site B to a maximum of 0.1821 Bq/L at Site D, and without exception, each of the five sites recorded concentrations that fell comfortably within the WHO gross-alpha screening level of 0.5 Bq/L (WHO, 2023), and well below the USEPA proposed radon MCL of 300 pCi/L (≈11.1 Bq/L) for public water systems (USEPA, 2003). It is noted that the WHO 0.5 Bq/L threshold applies to gross alpha radioactivity as a first-tier screening value, not to dissolved radon specifically.

On the basis of these data, it may be concluded that the borehole water sources serving Mubi-North Metropolis carry no measurable radiological threat to consumers at current concentration levels, and remain appropriate for both drinking and general household use. However, radon accumulation in groundwater is inherently dynamic; temporal changes driven by subsurface geological processes, rainfall-dependent recharge cycles, and local land-use pressures can shift concentrations in either direction. It is therefore recommended that structured, routine radiological monitoring of these water sources be institutionalised so that any upward trends in radioactivity are identified promptly and remedial action can be taken before public health thresholds are approached.

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