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# Radiological safety of drinking water sources in Nsukka metropolis based on natural radionuclide content

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## Abstract

**Background:** Naturally occurring radionuclides in drinking water represent a significant pathway for internal exposure to ionizing radiation. Their occurrence is largely controlled by geological and hydrogeochemical conditions, and prolonged ingestion at elevated concentrations may pose potential health risks.

**Objectives:** This study aimed to determine the activity concentrations of key naturally occurring radionuclides in selected groundwater and surface water sources in Nsukka Metropolis, Enugu State, Nigeria, and to evaluate their radiological safety in line with international guidelines.

**Methods:** Six water samples were purposively collected from three surface water sources (Ohe Nsukka Lake, Ajiye Odenigbo Pond, and Iyi Mkpi Stream) and three groundwater sources (Asho Spring, Iyi Adoro Spring, and University of Nigeria Nsukka Borehole). Activity concentrations of potassium-40 ($^{40}K$), radium-226 ($^{226}Ra$), and thorium-232 ($^{232}Th$) were determined using standard gamma spectrometry at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. Descriptive statistical analyses (mean, range, and variability) were performed and results were compared with internationally recommended reference levels.

**Results:** The activity concentrations varied across sampling locations, reflecting underlying geological heterogeneity. Potassium-40 recorded the highest activity concentrations (44.09–81.14 Bq/L), followed by thorium-232 (16.20–30.02 Bq/L), while radium-226 exhibited the lowest levels (10.22–24.21 Bq/L). Relatively higher radionuclide concentrations were observed in Asho Spring and Ajiye Odenigbo samples, suggesting localized geogenic influences. Despite this variability, all measured values were below internationally recommended guideline limits for drinking water quality.

**Conclusion:** The findings indicate that the investigated water sources in Nsukka Metropolis are radiologically safe for domestic consumption under current conditions. This study provides important baseline, radionuclide-specific data for an urbanizing region in southeastern Nigeria and enhances the evidence base for environmental radioactivity assessment. Continued monitoring and incorporation of dose-based risk evaluation are recommended to ensure sustained compliance with international radiation protection standards.

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**Keywords:** Environmental Radioactivity; Groundwater Contamination; Radiological Safety; Gamma Spectrometry; Nsukka

## 1. Introduction

Naturally occurring radionuclides are the primary source of human exposure to ionizing radiation worldwide, accounting for a significant portion of the average annual effective dose received by populations [1, 2]. These radionuclides are distributed throughout the Earth's crust and are present in varying concentrations in environmental media such as soil, air, and water. Ingestion through drinking water is a particularly important exposure pathway due to its chronic and cumulative effects on public health [3].

Key naturally occurring radionuclides—including potassium-40 ($^{40}K$), radium-226 ($^{226}Ra$), and thorium-232 ($^{232}Th$)—originate from long-lived radioactive decay chains that have existed since the formation of the Earth. These radionuclides are commonly found in geological formations and can enter groundwater and surface water systems through geochemical processes such as mineral weathering, rock–water interaction, ion exchange, and dissolution under different physicochemical conditions [4, 5]. As a result, their presence in drinking water is largely determined by the local geology and hydrogeochemical environment.

The distribution and concentration of radionuclides in water are influenced by factors such as lithology, aquifer properties, redox conditions, and water residence time [3, 4]. In regions underlain by sedimentary and metamorphic rocks—such as southeastern Nigeria—naturally occurring radioactive materials (NORMs) can vary significantly, leading to heterogeneous radionuclide concentrations even within small areas [6, 7]. This variability highlights the need for site-specific assessments to accurately estimate radiological exposure and associated health risks [1]. Previous studies in Nigeria have generally found natural radionuclide concentrations in drinking water to be within recommended safety limits, though regional differences exist [8, 5, 7]. Most of these studies have focused on gross alpha and beta activity, with limited data on specific radionuclide concentrations that allow direct comparison with international guidelines [3, 4].

Previous studies in Nsukka Metropolis have predominantly focused on either groundwater systems (e.g., hydrogeological and hydrochemical assessments) or surface water sources such as springs, with little evidence of integrated studies evaluating both water sources within a unified framework [9, 10]. This contrasts with studies from other parts of Nigeria where combined surface and groundwater assessments have been conducted [11]. To address these gaps, this study provides a comparative assessment of the activity concentrations of $^{40}K$, $^{226}Ra$, and $^{232}Th$ in selected groundwater and surface water sources in Nsukka Metropolis. By integrating multiple water source types and directly comparing measured concentrations with international reference levels [1, 3], this work establishes a location-specific baseline for environmental radioactivity and informs future monitoring, regulatory assessment, and public health risk evaluation in southeastern Nigeria.

## 2. Materials and methods

### 2.1. Study Area

The study was conducted in Nsukka Metropolis, Enugu State, southeastern Nigeria. Nsukka lies within the Anambra Basin and is underlain predominantly by Upper Cretaceous sedimentary formations, particularly the Ajali and Nsukka Formations, which consist mainly of sandstones interbedded with shale, siltstone, and minor coal seams [12, 13]. These lithological units are known to host varying concentrations of naturally occurring radioactive materials (NORMs), which may influence radionuclide mobility into surface water and groundwater systems. The metropolis is a rapidly expanding urban and agricultural center, with increasing dependence on diverse water sources for domestic use.

### 2.2. Study Design and Sampling Strategy

A prospective cross-sectional environmental study design was adopted. Six representative water sources were purposively selected to capture both surface water and groundwater pathways commonly used for domestic supply within the metropolis. Surface water samples were collected from Ohe Nsukka Lake, Ajiye Odenigbo Pond, and Iyi Mkpi Stream, while groundwater samples were obtained from Asho Spring, Iyi Adoro Spring, and the University of Nigeria Nsukka (UNN) Borehole. The selection criteria included frequency of community use, accessibility, and hydrogeological representativeness.

### 2.3. Sample Collection and Preservation

Water samples were collected following internationally accepted protocols for radionuclide analysis in environmental waters. Pre-cleaned 2litre high-density polyethylene containers were used for sampling. Prior to collection, each container was thoroughly washed with detergent, rinsed with deionized water, and finally rinsed with the respective water sample to minimize contamination.

Approximately 10 ml of concentrated nitric acid ($HNO_3$) was added to each sample immediately after collection to acidify the water to pH < 2. This acidification prevents radionuclide adsorption onto container walls and inhibits microbial activity. For borehole samples, the tap was flushed for at least 3 minutes prior to collection to remove stagnant water and ensure a representative sample. All samples were then tightly sealed, labeled, and transported in insulated containers to the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria, Nigeria, for laboratory analysis.

### 2.4. Gamma Spectrometric Analysis

Activity concentrations of potassium-40 ($^{40}K$), radium-226 ($^{226}Ra$), and thorium-232 ($^{232}Th$) were determined using high-resolution gamma-ray spectrometry at CERT. The measurement system consisted of a sodium iodide [NaI(Tl)] detector coupled to a multichannel analyzer and appropriate shielding to reduce background radiation. Prior to analysis, samples were transferred into standard Marinelli beakers, sealed, and stored for a minimum of 28 days to allow secular equilibrium between parent radionuclides and their respective progenies.

Energy and efficiency calibrations of the spectrometric system were performed using certified reference materials with known gamma-ray energies and activities. The radionuclides were quantified using their characteristic gamma emission peaks: 1460 keV for $^{40}K$, the gamma lines of $^{214}Pb$ and $^{214}Bi$ (as proxies for $^{226}Ra$), and the gamma emissions of $^{228}Ac$ (as an indicator for $^{232}Th$). Each sample was counted for a sufficient live time to achieve acceptable counting statistics, and background spectra were subtracted from the sample spectra prior to analysis.

Activity concentrations (Bq/L) were calculated using standard equations that account for net count rates, detector efficiency, gamma emission probability, sample volume, and counting time. Measurement uncertainties were evaluated by propagating statistical counting errors and calibration uncertainties.

### 2.5. Data Analysis

Descriptive statistical analyses, including mean values and standard deviations, were computed using Microsoft Excel 2021. The measured activity concentrations were compared with international reference levels recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) to evaluate radiological safety.

## 3. Result

**Table 1** The concentration of potassium radionuclide concentration in the various water sample

| SAMPLE ID | K-40(Bq/L) | ERROR±(Bq/L) |
|---|---|---|
| ASHO | 81.14152 | 3.763608 |
| OHE NSUKKA | 74.58787 | 3.723173 |
| IYI ADORO | 57.61431 | 2.489911 |
| UNN BOREHOLE | 44.09331 | 2.659409 |
| AJIYE ODENIGBO | 59.21773 | 3.250389 |
| IYI MKPI | 54.96734 | 3.265941 |

Table 1 above shows the concentration of Potassium-40 radionuclide across the six water samples, with concentrations expressed in Becquerel per litre (Bq/L). The ASHO water sample recorded the highest potassium-40 concentration (81.14 Bq/L), while the UNN Borehole sample had the lowest (44.09 Bq/L). All potassium-40 concentrations in the water samples are well below the UNSCEAR-2000 safety limit of 400 Bq/L, indicating that these water sources are safe with respect to potassium-40 activity.

**Table 2 T**he concentration of Radium-226 in the various water samples collected

| SAMPLE ID | Rad-226(Bq/L) | ERROR±(Bq/L) |
|---|---|---|
| ASHO | 18.00579 | 1.316338 |
| OHE NSUKKA | 17.02781 | 1.42526 |
| IYI ADORO | 10.85979 | 1.117034 |
| UNN BOREHOLE | 23.65469 | 2.271147 |
| AJIYE ODENIGBO | 24.20973 | 2.666281 |
| IYI MKPI | 10.21611 | 1.216686 |

Table 2 displays the concentration of Radium-226 (^226^Ra) in the water samples. The highest activity was observed in Ajiye Odenigbo (24.21 ± 2.67 Bq/L), while the lowest was in Iyi Mkpi (10.22 ± 1.22 Bq/L). All measured Ra-226 concentrations are below the UNSCEAR-2000 safety limit of 40 Bq/L, indicating that the water samples are safe with respect to radium-226 activity.

**Table 3** The concentration of thorium-232 in the various water samples

| SAMPLE ID | Th-232(Bq/L) | ERROR±(Bq/L) |
|---|---|---|
| ASHO | 16.20182 | 1.516534 |
| OHE NSUKKA | 21.93843 | 1.702395 |
| IYI ADORO | 25.72292 | 2.342075 |
| UNN BOREHOLE | 24.10490 | 2.559863 |
| AJIYE ODENIGBO | 20.78677 | 1.185861 |
| IYI MKPI | 30.0179 | 2.968073 |

Table 3 shows the concentration of thorium-232 (^232^Th) in the collected water samples. The highest activity concentration was found in Iyi Mkpi (30.02 ± 2.97 Bq/L), and the lowest in Asho (16.20 ± 1.52 Bq/L). All Th-232 concentrations are below the UNSCEAR-2000 safety limit of 40 Bq/L, indicating that the water samples are safe with respect to thorium-232 activity.

**Table 4** The activity concentration of each of the radionuclide constituent in each sample and the total of each radionuclide constituent

| SAMPLE ID | K-40 ± Error (Bq/L) | Ra-226 ± Error (Bq/L) | Th-232 ± Error (Bq/L) |
|---|---|---|---|
| ASHO | 81.14152± 3.763608 | 18.00579± 1.316338 | 16.20182± 1.516534 |
| OHE NSUKKA | 74.58787± 3.723173 | 17.02781± 1.42526 | 21.93843± 1.702395 |
| IYI ADORO | 57.61431±2.489911 | 10.85979±1.117034 | 25.72292±2.342075 |
| UNN BOREHOLE | 44.09331± 2.659409 | 23.65469± 2.271147 | 24.10490± 2.559863 |
| AJIYE ODENIGBO | 59.21773± 3.250389 | 24.20973± 2.666281 | 20.78677± 1.185861 |
| IYI MKPI | 54.96734± 3.265941 | 10.21611± 1.216686 | 30.0179± 2.968073 |

Table 4 summarizes the total activity concentrations of each radionuclide across all samples, measured in Bq/L. Potassium-40 exhibited the highest total activity (371.62 ± 19.15 Bq/L), followed by thorium-232 (138.77 ± 12.27 Bq/L), and radium-226 (103.97 ± 10.01 Bq/L).

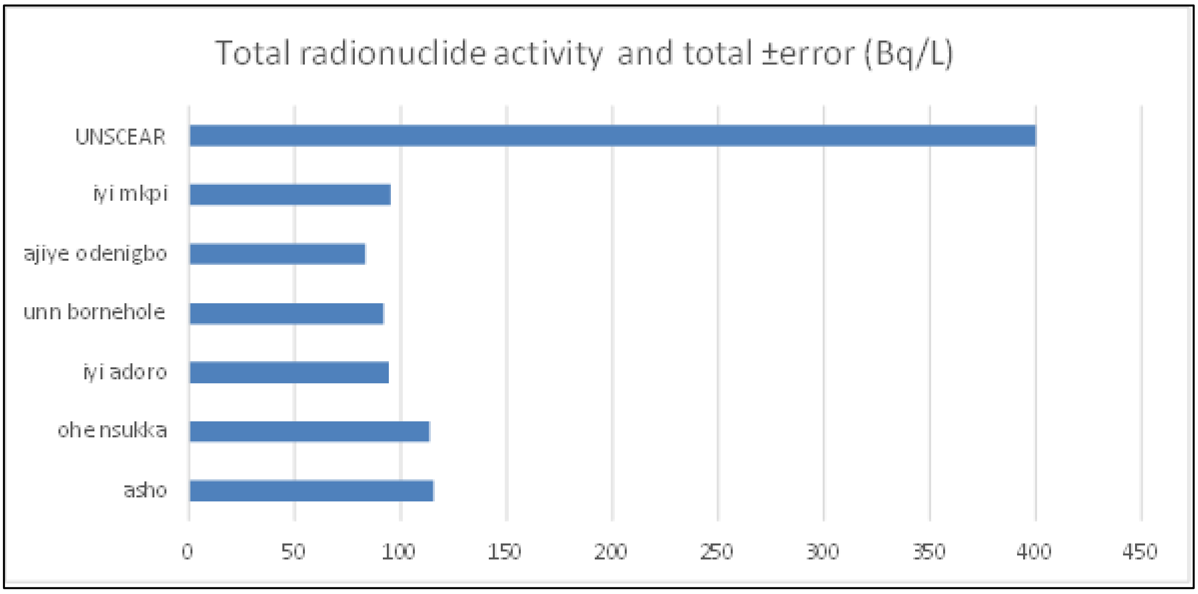


**Figure 1** The radionuclide activity of water sample from each of the water samples as compared with the UNCLEAR acceptable standard

The figure above demonstrates that all samples fall within the international safety margin of less than 400 Bq/L, indicating that none of the sampled areas pose a significant risk of radioactive exposure.

## 4. Discussion

This study provides a radionuclide-specific evaluation of natural radioactivity in selected groundwater and surface water sources within Nsukka Metropolis, offering updated baseline data for an urbanizing region in southeastern Nigeria. The presence of potassium-40 ($^{40}$K), radium-226 ($^{226}$Ra), and thorium-232 ($^{232}$Th) in all sampled locations confirms their ubiquitous occurrence in environmental media and highlights the influence of geological and hydrogeochemical processes on radionuclide mobilization into water systems [1, 4].

Among the analyzed radionuclides, $^{40}$K exhibited the highest activity concentrations across all sampling points, with values ranging from 44.09 to 81.14 Bq/L. This dominance is consistent with its natural abundance in potassium-bearing minerals such as feldspars and micas, as well as its relatively high solubility and mobility in aqueous environments. The elevated contribution of $^{40}$K to total radioactivity in water has been widely reported in similar geological settings, both within Nigeria and globally [5, 4]. The relatively higher concentration observed at Asho may reflect localized lithological characteristics or enhanced mineral–water interaction, possibly due to longer groundwater residence time or increased weathering intensity. These findings reinforce the role of geogenic factors in controlling radionuclide distribution and provide site-specific validation of earlier regional observations.

In contrast, $^{226}$Ra and $^{232}$Th showed comparatively lower activity concentrations, with $^{226}$Ra ranging from 10.22 to 24.21 Bq/L and $^{232}$Th from 16.20 to 30.02 Bq/L. The relatively lower concentrations of $^{226}$Ra can be attributed to its geochemical behavior, particularly its limited mobility under oxidizing conditions and its tendency to co-precipitate with barium or adsorb onto aquifer matrices [4, 3]. Similarly, the low concentrations of $^{232}$Th are expected due to its strong particle reactivity, low solubility, and preferential association with solid phases, which significantly restrict its transport in aqueous systems [1]. Despite these lower concentrations, the detection of $^{226}$Ra in all samples remains radiologically important because of its alpha-emitting properties and its known bioaccumulation in bone tissue following ingestion, posing potential long-term health risks if concentrations exceed guideline levels [3].

A key observation from this study is the spatial variability in radionuclide activity concentrations across the sampled locations. For example, Ajiye Odenigbo and the UNN borehole exhibited relatively higher $^{226}$Ra concentrations, while Iyi Mkpi had the highest $^{232}$Th activity. This variability reflects differences in subsurface geology, aquifer composition, and hydrogeochemical conditions—such as pH, redox potential, and ionic composition—which influence radionuclide solubility, speciation, and mobility. As a result, localized differences can occur even within a small geographic area [4, 1], highlighting the importance of site-specific assessments over generalized regional averages for radiological risk evaluation.

Another important contribution of this study is the integrated assessment of both groundwater and surface water sources within the same urban environment. Previous studies in Nigeria have often been limited to either groundwater systems or gross alpha and beta activity measurements, which do not provide radionuclide-specific insights necessary for detailed comparison with international standards [8,7]. By quantifying specific radionuclides, the present study enables direct comparison with guideline values and enhances the reliability of radiological risk assessment.

When compared with international reference levels, the activity concentrations of all measured radionuclides were found to be below recommended limits. Specifically, $^{40}$K concentrations were well below the UNSCEAR reference level of 400 Bq/L, while $^{226}$Ra and $^{232}$Th concentrations remained below the commonly cited screening levels of 40 Bq/L [1, 3]. This indicates that the measured activity concentrations in the studied water sources are below internationally recommended guideline values under current exposure conditions. However, it is important to note that radiological safety assessments should ideally incorporate dose calculations (e.g., annual effective dose and lifetime cancer risk) for a more comprehensive evaluation of health implications.

Furthermore, the cumulative radionuclide activity results demonstrate that $^{40}$K is the dominant contributor to total radioactivity, followed by $^{232}$Th and $^{226}$Ra. While $^{40}$K contributes significantly to total activity, its radiological impact is generally lower compared to alpha-emitting radionuclides such as $^{226}$Ra, which have higher biological effectiveness [3]. Therefore, risk assessment should not rely solely on activity concentration magnitudes but also consider radiation type and biological impact.

Although the current findings indicate radiological safety, the observed variability and the increasing anthropogenic pressures associated with urbanization, agriculture, and groundwater exploitation in Nsukka Metropolis necessitate continuous monitoring. Changes in land use, waste disposal practices, and hydrogeological conditions may alter radionuclide concentrations over time [4]. Establishing this baseline dataset is therefore crucial for future comparative studies and for early detection of any deviations that may pose health risks.

## 5. Conclusion

This study provides a comprehensive radionuclide-specific assessment of natural radioactivity in selected groundwater and surface water sources within Nsukka Metropolis, southeastern Nigeria. The detection of potassium-40 ($^{40}$K), radium-226 ($^{226}$Ra), and thorium-232 ($^{232}$Th) across all sampled locations confirms their ubiquitous occurrence and underscores the influence of local geological formations and hydrogeochemical processes on their distribution in water systems. The observed spatial variability among sampling points further highlights the heterogeneity of aquifer characteristics and the need for site-specific evaluations in radiological studies.

Despite these variations, the measured activity concentrations of all radionuclides were below internationally recommended reference levels for drinking water quality, indicating that the studied water sources are radiologically safe for domestic consumption under current conditions. Notably, $^{40}$K was identified as the dominant contributor to total radioactivity, although its radiological impact is generally lower than that of alpha-emitting radionuclides such as $^{226}$Ra, which remain important from a health risk perspective due to their biological behavior.

A key strength of this study lies in its integrated assessment of both groundwater and surface water sources within a single urban setting, as well as the provision of radionuclide-resolved activity concentrations. This approach enhances comparability with international standards and improves the reliability of radiological risk evaluation compared to studies based solely on gross alpha and beta measurements. Furthermore, the dataset generated establishes an important baseline for environmental radioactivity in Nsukka Metropolis, an area experiencing increasing urbanization and agricultural activities.

Overall, the findings contribute to the growing body of knowledge on environmental radioactivity in Nigeria and provide a valuable reference for regulatory authorities and public health stakeholders. However, given the dynamic nature of environmental systems and the potential influence of anthropogenic activities, periodic monitoring of drinking water sources is strongly recommended. Future studies should incorporate radiological dose assessments and long-term surveillance to ensure that radiation exposure remains within safe limits and continues to adhere to the principle of keeping exposures as low as reasonably achievable (ALARA) in line with international best practices.

## Compliance with ethical standards

### *Disclosure of conflict of interest*

There is no conflict of interest with the authors of this work whatsoever.

### *Statement of ethical approval*

Ethical approval for the study was obtained from the Faculty of Health Sciences Ethics Committee, Nnamdi Azikiwe University, Nnewi Campus. Community consent was also secured prior to sample collection.

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