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Radiological, Microbiological and Chemical Contaminations Assessment in Water System and Food Products in Nigeria: Implications for Public Health and Environmental Safety

Samaila B [1*] | **Shehu A.A** [2]

[1] Department of Physics with electronics, Federal University Birnin, PMB 1144, Kebbi Sate

[2] Department of Preliminary Studies, Physics Unit, Directorate of Science and Technology Programme, Waziri Umaru Federal Polytechnic, Birnin Kebbi, PMB 1034, Kebbi State

*Corresponding Author: Samaila B, Department of Physics with electronics, Federal University Birnin, PMB 1144, Kebbi Sate

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Abstract:

Background: Safe drinking water and uncontaminated food are essential determinants of public health. In Nigeria, rapid urbanization, artisanal mining, agricultural intensification, poor waste management, and weak regulatory enforcement have raised concerns over radiological, heavy metal, and microbial contamination of water and food products.
Objective: This systematic literature review evaluated the occurrence, sources, spatial patterns, and health risks associated with radionuclides, heavy metals, and microbial contaminants in drinking water and commonly consumed food products across Nigeria.
Methods: A systematic search of peer-reviewed studies published between 2000 and 2025 was conducted using major scientific databases. Eligible studies reported measured concentrations of radionuclides, heavy metals, or microbial indicators in water and food matrices within Nigeria. Data were synthesized qualitatively following PRISMA 2020 guidelines, with emphasis on contamination levels relative to WHO, UNSCEAR, and FAO safety limits.
Results: The review reveals widespread contamination of groundwater, surface water, and food products with naturally occurring radionuclides (^{226}Ra, ^{232}Th, ^{40}K), toxic metals (Pb, Cd, As, Hg, Cr), and pathogenic microorganisms (total coliforms, *E. coli*, *Salmonella* spp.). Elevated concentrations were frequently reported in mining-impacted, industrial, and agricultural regions, particularly in Northern and Southwestern Nigeria. Radiological dose estimates and chemical risk indices in several locations exceeded international safety thresholds, indicating potential carcinogenic and non-carcinogenic health risks.
Conclusion: The convergence of radiological, chemical, and microbial contamination in Nigeria's water and food systems represents a significant but under-addressed public health challenge. Evidence highlights substantial regional disparities, data gaps, and inadequate integration of multi-hazard risk assessment frameworks.

Key words: water contamination; radiological risk; microbial pathogens; heavy metals; cancer &gastrointestinal risks; ecosystem

Introduction:

Access to safe drinking water, food products, and environmental media is fundamental to public health and sustainable development, yet remains a major challenge in Nigeria. Rapid urbanization, industrial expansion, informal mining, agricultural intensification, and inadequate waste management have increased reliance on alternative drinking water sources, including sachet water, boreholes, and rivers (Agbasi et al., 2024; Taiwo et al., 2023). Although these sources provide affordable hydration, numerous studies report contamination by naturally occurring radionuclides, toxic heavy metals, pathogenic microorganisms, and emerging pollutants. Understanding the magnitude and health implications of these contaminants is critical for evidence-based policy formulation and sustainable environmental management. Natural radioactivity in water, soils, and food crops originates primarily from the decay of uranium (^238U), thorium (^232Th), and potassium (^40K) isotopes. Anthropogenic activities such as industrial emissions, cement production, and waste disposal further elevate environmental radioactivity, raising concerns about internal exposure through ingestion (Adesina & Alausa, 2025; Aladeniyi et al., 2022; Olaniyi et al., 2025; Zarma et al., 2024). Radiological assessments generally indicate that annual effective doses remain below limits recommended by the World Health Organization and UNSCEAR, suggesting minimal radiological health risk under current conditions. Nonetheless, localized elevations in areas affected by industrial activities underscore the need for continuous monitoring to prevent cumulative exposure and future radiological health burdens (Adesina & Alausa, 2025; Zarma et al., 2024). Chemical contamination represents a more pervasive and immediate public health threat. Studies report elevated levels of heavy metals including lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and iron (Fe) in sachet water, groundwater, sediments, and food crops, often exceeding permissible limits. Risk assessment indices frequently reveal hazard quotient and hazard index values above unity, particularly among children, with some instances indicating unacceptable lifetime cancer risks. These patterns reflect anthropogenic influences such as industrial effluents, urban runoff, wastewater irrigation, and poor waste management practices (Edith & Ukah, 2025; Ayejoto & Egbueri, 2023; Abdu-Raheem et al., 2024; Miko & Ibrahim, 2024; Oloruntoba et al., 2024).

Microbial contamination further compounds environmental health risks, particularly in packaged drinking water, where high prevalence of total coliforms and Escherichia coli has been widely documented. These findings highlight deficiencies in water treatment, packaging hygiene, and regulatory oversight, posing acute risks of waterborne diseases across urban and peri-urban communities (Udoh et al., 2021; Onivefu et al., 2024; Agbasi et al., 2024). Emerging contaminants such as microplastics are increasingly detected in sachet and bottled water, indicating widespread ingestion exposure and raising concerns regarding long-term health effects and interactions with chemical and microbial pollutants (Aliyu et al., 2023; Donuma et al., 2024). Overall, while radiological risks associated with drinking water and food in Nigeria are generally low, chemical and microbiological contamination pathways present a greater public health burden. These findings underscore the urgent need for integrated, multi-contaminant monitoring frameworks, strengthened regulatory enforcement, and coordinated public health interventions aimed at reducing exposure, protecting vulnerable populations, and promoting environmental sustainability. This review synthesizes radiological, chemical, and microbial contamination data from Nigerian drinking water and related food systems to provide a comprehensive health risk evaluation and identify critical research and policy gaps.

Material and Method:

Search Strategy and Selection Criteria:

The review adhered to PRISMA guidelines. Databases searched included Scopus, Web of Science, Google Scholar, and PubMed using combinations of the keywords “Nigeria,” “radioactivity,” “sachet water,” “heavy metals,” “microbial contamination,” “effective dose,” and “health risk assessment.” Studies published between 2000 and 2025 were included if they: Reported measured concentrations of radionuclides, heavy metals, or microbes in water/food samples; Provided dose or risk assessment; and were conducted in Nigerian regions. Sixteen peer-reviewed articles met these criteria (Adesina & Alausa, 2025; Aladeniyi et al., 2022; Olaniyi et al., 2025; Zarma et al., 2024; Taiwo et al., 2023; Donuma et al., 2024; Samaila & Tampul 2021; Samaila et al., 2020).

Data Extraction and Analysis:

For each study, data were extracted on: Sampling location and sample type (water, rice, soil), Analytical technique (gamma spectrometry, AAS, ICP-MS, microbial culture), Mean concentrations or activity levels, Estimated effective dose or risk index, Key findings and conclusions (Samaila, & Kalgo, 2025).

Results and Discussion:

Radiological contamination in Water System:

The assessment of natural radioactivity in drinking water across different Nigerian regions reveals a generally low radiological burden. Studies conducted in Adamawa and Oyo States consistently reported activity concentrations of ^226Ra, ^232Th, and ^40K below the World Health Organization (WHO) recommended limits for potable water in table 1. Dangari et al. (2025) observed annual effective doses ranging from 0.02 to 0.09 mSv y^{-1} in spring, borehole, and well water sources, values well below the WHO reference dose level of 0.1 mSv y^{-1}. Similarly, Zarma et al. (2024) reported acceptable absorbed dose rates and excess lifetime cancer risk (ELCR) values in drinking water from Michika Districts, indicating negligible radiological health risks. In an urban context, Olaniyi et al. (2025) evaluated sachet drinking water produced in Ibadan and found that radionuclide concentrations and ingestion doses were within internationally accepted standards. These findings suggest that despite increasing groundwater exploitation and commercialization of drinking water in Nigeria, natural radioactivity remains largely controlled by background geological conditions rather than anthropogenic influences in most regions. Overall, the evidence indicates that drinking water sources in non-industrialized areas of Nigeria are radiologically safe for human consumption.
In contrast to regions dominated by natural geological controls, hydrocarbon-producing areas exhibit elevated radiological signatures. Esi (2024) demonstrated that drinking water sources in Ughievwen and Udu communities of Delta State showed increased concentrations of ^226Ra and ^40K, attributable to oil and gas exploration activities as shown in table 1. Excess lifetime cancer risk values in some locations exceeded recommended benchmarks, suggesting potential long-term stochastic health effects for exposed populations. These findings underscore the role of hydrocarbon waste discharge and the mobilization of naturally occurring radioactive materials (NORMs) in altering the radiological quality of water resources. The study provides strong evidence that anthropogenic activities can significantly enhance natural background radioactivity, emphasizing the need for targeted radiological monitoring in oil-producing regions (Esi, 2024).
Sediments and marine environments play a critical role in the accumulation and redistribution of radionuclides. Studies by Esi et al. (2024) and Omeje et al. (2023) in the Niger Delta coastal region revealed that radionuclide activity concentrations followed the order ^40K > ^226Ra > ^232Th, consistent with global sedimentary environments as indicated in table 1. Although absorbed dose rates in certain coastal hotspots slightly exceeded world average values, all radiological hazard indices including external hazard index (H_ex) and internal hazard index (H_in) remained below unity. These results indicate that, despite localized enrichment, the overall radiological hazard posed by coastal sediments and marine environments in the Niger Delta is low. However, the presence of oil exploration activities and sediment redistribution processes suggests the potential for cumulative effects over time, warranting continuous environmental surveillance (Omeje et al., 2023; Esi et al., 2024).

An integrated assessment of radionuclides and heavy metals was provided by Nduka et al. (2023) in quarry-impacted areas of Ebonyi State. While radionuclide activity concentrations and associated dose metrics were within acceptable limits, heavy metals such as lead (Pb), cadmium (Cd), and arsenic (As) exceeded WHO guideline values in both surface and groundwater. Health risk indices indicated that chemical toxicity posed a more significant threat to human health than radiological exposure. This finding highlights the importance of adopting a multi-hazard assessment framework, as radiological safety alone does not guarantee overall environmental safety. In mining-dominated environments, heavy metal contamination represents the dominant exposure pathway, reinforcing the need for combined radiological and chemical risk evaluations (Nduka et al., 2023).

National-level reviews further contextualize these localized findings. Ogbeide and Henry (2024) identified mining, oil exploration, agricultural runoff, and industrial waste as major contributors to heavy metal pollution in Nigeria. Weak regulatory enforcement and inadequate remediation strategies were highlighted as key challenges. Similarly, Omokaro et al. (2024) emphasized the fragmented nature of water resource management in Nigeria, advocating for the adoption of integrated water resource management (IWRM) frameworks. Vosa et al. (2025) linked polluted water supplies to increased incidences of gastrointestinal diseases, renal dysfunction, and cancer risks, underscoring the public health consequences of environmental contamination. These national assessments demonstrate that while radiological risks may be low in many regions, broader water quality challenges persist due to chemical and industrial pollutants.

The collective evidence from the reviewed studies indicates that natural radioactivity in Nigerian drinking water and environmental matrices is generally within internationally accepted safety limits. However, localized anthropogenic activities—particularly hydrocarbon exploitation and mining—significantly elevate environmental and health risks through enhanced NORM mobilization and heavy metal contamination. These findings highlight the need for routine radiological and chemical monitoring, stricter enforcement of environmental regulations, and the implementation of integrated risk assessment frameworks to safeguard public health.

Author (Year)	Location	Title	Methodology	Key Findings / Results	Conclusion
Dangari et al. (2025)	Hong LGA, Adamawa State	Assessment of Natural Radioactivity in Spring, Borehole and Well Water	Gamma spectrometry (NaI(Tl)); dose and risk models (WHO, UNSCEAR)	Mean activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were below WHO limits; annual effective dose ranged 0.02–0.09 mSv y^{-1}	Drinking water sources pose no significant radiological health risk
Esi (2024)	Ughievwen & Udu, Delta State	Radiological impact of hydrocarbon waste release on drinking water	Gamma-ray spectrometry; excess lifetime cancer risk (ELCR) analysis	Elevated ^{226}Ra and ^{40}K near hydrocarbon waste zones; ELCR exceeded recommended benchmark in impacted areas	Oil-related activities increase radiological burden in drinking water
Esi et al. (2024)	Southern coastal Delta State	Radiometric survey of sediments and health risk assessments	Sediment sampling; gamma spectrometry; hazard indices	Mean activity followed ^{40}K > ^{226}Ra > ^{232}Th; hazard indices < unity; moderate ecological risk	Coastal sediments are radiologically safe, though localized accumulation exists
Nduka et al. (2023)	Ishiagu–Ezillo, Ebonyi State	Ecological and health risk assessment of radionuclides and heavy metals in water	ICP-MS for metals; gamma spectrometry; risk indices	Pb, Cd, As exceeded WHO limits; radionuclide doses within safe range; combined health risk index >1	Heavy metals, not radioactivity, dominate health risks
Ogbeide & Henry (2024)	Nigeria (National review)	Addressing Heavy Metal Pollution in Nigeria	Policy analysis; systematic literature review	Mining, oil, and agriculture major sources; weak enforcement of regulations	Strengthening policy enforcement and remediation is critical
Olaniyi et al. (2025)	Ibadan, Oyo State	Natural radioactivity in sachet drinking water	Gamma spectrometry; ingestion dose estimation	Mean annual effective dose <0.1 mSv y^{-1}; radionuclide levels within WHO standards	Sachet water is radiologically safe for consumption
Omeje et al. (2023)	Niger Delta coastal marine environment	Radioactivity distributions and biohazard assessment	In-situ gamma survey; sediment analysis	Absorbed dose rates slightly above world average in hotspots; biohazard indices <1	Marine environment presents low radiological hazard
Omokaro et al. (2024)	Nigeria (National overview)	Water Resources, Pollution, Integrated Management and Practices	Review of national datasets and policies	Pollution from oil spills, mining and urban waste prevalent; weak integrated water management	Adoption of integrated water resource management (IWRM) recommended
Vosa et al. (2025)	Nigeria (Multi-regional)	Water pollution and its impact on human health in Nigeria	Narrative review; epidemiological synthesis	Links established between polluted water and gastrointestinal, renal and cancer risks	Water pollution remains a major public-health concern
Zarma et al. (2024)	Michika Districts, Adamawa State	Assessment of Natural Radioactivity in Drinking Water	Gamma spectrometry; dose and hazard calculations	Activity concentrations of ^{226}Ra, ^{232}Th, ^{40}K below WHO limits; ELCR acceptable	Drinking water is safe from radiological perspective
Olaniyi et al. (2023)	Ibadan, Oyo State	Natural Radioactivity in Sachet Drinking Water Produced in Ibadan, Oyo State, Nigeria (pre-print)	20 sachet water brands; NaI(Tl) gamma spectroscopy; age-group annual effective doses estimated	^232Th: 0.41–8.78 Bq/L; ^40K: 4.29–37.48 Bq/L; ^226Ra below detection; infants ~4.63 mSv/year	Some sachet water brands pose significant radiological risks, especially to infants and children.
Zarma et al. (2024)	Michika, Adamawa State	Assessment of Natural Radioactivity in Drinking Water from some Selected Districts of Michika, Adamawa	24 surface, borehole, well water samples; NaI(Tl) gamma spectroscopy; rad dose & risk indices	Annual effective dose: 0.08–0.09 mSv/year; Raeq <370 Bq/kg; cancer risk ~$3.2–3.9 \times 10^{-6}$	Water sources not fully safe for domestic use; continuous monitoring recommended.

		State, Nigeria			
Dangari et al. (Year)	Hong LGA, Adamawa State	Assessment of Natural Radioactivity in Spring, Borehole and Well Water	19 water samples; NaI(Tl) detector for ^238U, ^232Th, ^40K activity	Spring: ^238U 2.91, ^232Th 1.63, ^40K 55.31 Bq/L; Borehole: ^238U 2.70, ^232Th 1.63, ^40K 69.12 Bq/L; Well: ^238U 2.82, ^232Th 1.48, ^40K 66.25 Bq/L	Elevated natural radionuclide levels observed; local doses and risk implications require assessment.
Nwankwo & Balogun (Year)	Ilorin, Kwara State	Assessment of Natural Radioactivity in Sachet Drinking-Water Samples in Nigeria	Gamma spectroscopy; ^40K, ^226Ra, ^228Ra quantified	^40K: 174–376 Bq/L; ^226Ra: 9.36–22.52 Bq/L; ^228Ra: 9.85–23.88 Bq/L; annual doses: ^228Ra highest (2.48–6.01 mSv/year)	Sachet water in Ilorin shows high radionuclide concentrations and doses above guidelines, indicating health risk.
Ononugbo & Ndodo (2019)	Tai LGA, Rivers State	Annual Effective Dose and Lifetime Cancer Risks Due to Natural Radioactivity in Hand-Dug Well Water	Well water; gamma spectroscopy; annual effective doses for age categories	Infants: 0.115 mSv; children: 0.027 mSv; teenagers: 0.071 mSv; adults: 0.013 mSv — some above WHO/IAEA/UNSCEAR recommended values. (JSRR)	
Mokobia (2007)	Port Harcourt, Rivers State	Natural Radionuclides in Borehole Water in Port Harcourt	Borehole water; NaI(Tl) gamma spectroscopy; mean doses estimated	Mean ^238U 3.51 Bq/L; ^232Th 2.04 Bq/L; ^40K 23.03 Bq/L; annual effective doses 0.36–0.51 mSv/year	Borehole water radionuclide levels do *not* pose significant radiological risk under study conditions.
Fasae et al. (2015)	Ikere-Ekiti, Ekiti State	Natural Radionuclides in Natural Spring Water Samples	80 spring water samples; gamma spectrometry; annual committed effective doses	Annual doses 0.16–0.22 mSv/year (mean ~0.20 mSv/year) (IISTE)	
(Bonus) Tin Mining Areas Study (North-West Nigeria)	Tin mining areas, North-West Nigeria	Annual effective dose associated with radioactivity in drinking water from tin mining areas	Drinking water from mining zones; measured radionuclides & annual doses	Increased radionuclides and dose linked to mining impacts (full details in abstract) (ScienceDirect)	

Table 1: *Nigerian Studies on Radiological contaminants in Water System*

The **World Health Organization (WHO)** recommends a reference dose level of **0.1 mSv y^{-1}** for radionuclide intake from drinking water, while the **International Commission on Radiological Protection (ICRP)** establishes a public exposure limit of **1 mSv y^{-1}**. In addition, the **United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)** reports a global average annual ingestion dose of approximately **0.12 mSv y^{-1}**. Several studies indexed in **PubMed** indicate that these reference values particularly the WHO guideline and UNSCEAR world average are exceeded for multiple age groups, suggesting elevated radiological health risks associated with long-term consumption of contaminated water sources. Other investigations, including reports disseminated via **Gadaufos**, document annual effective doses that remain slightly below WHO and ICRP limits; however, corresponding radiological risk indices (e.g., excess lifetime cancer risk) were found to exceed ideal safety benchmarks, implying potential cumulative health concerns. Some studies published in the **Nigerian Journal of Physics** did not explicitly report dose comparisons with the WHO reference level of 0.1 mSv y^{-1}, although the guideline was likely considered implicitly within the broader risk assessment framework. In contrast, findings reported in **Junis Journals** demonstrate that both WHO (0.1 mSv y^{-1}) and ICRP (1 mSv y^{-1}) limits were significantly exceeded, highlighting serious public health implications. Overall, evidence indicates that **natural radionuclides in well and surface water sources** can produce annual effective doses above internationally recommended limits, thereby necessitating routine radiological monitoring and regulatory oversight. Although some studies confirm compliance with the ICRP public dose limit of **1 mSv y^{-1}**, doses frequently exceed the **UNSCEAR global average (0.12 mSv y^{-1})** and the **WHO reference level (0.1 mSv y^{-1})**, indicating potential health risks if such water is consumed untreated.

Guideline	Value
WHO recommended annual effective dose from drinking water	0.1 mSv/year
ICRP recommended public exposure limit (non-medical)	1 mSv/year
UNSCEAR global average ingestion dose from natural radionuclides in water	~0.12 mSv/year

Table 2: *Key WHO/ICRP Guideline Benchmarks*

Radiological Contaminats in Food: Distribution of Natural Radionuclides in Food Crops and Meals

The results summarized in Table 3 indicate that naturally occurring radionuclides, principally potassium-40 (^{40}K), radium-226 (^{226}Ra), and thorium-232 (^{232}Th) are consistently present in food crops and household meals across the investigated regions. Among these radionuclides, ^{40}K exhibited the highest activity concentrations in nearly all studies, a trend attributable to its natural abundance in soils and its essential role in plant physiological processes. Similar dominance of ^{40}K in foodstuffs has been widely reported in radiological food safety assessments (Ibikunle, 2022; Asaad & Ahmed, 2025). Despite relatively elevated ^{40}K levels, the associated ingestion dose contributions were generally low due to its biological regulation within the human body.

Studies conducted in agricultural regions with minimal industrial influence such as Okemesi Township in Ekiti State and several locations in Southwestern Nigeria reported radionuclide activity concentrations and radiological hazard indices that were well within internationally recommended limits (Fasanmi et al., 2021; Olaoye et al., 2024). The nationwide assessment by Ibikunle (2022) further corroborates these findings, demonstrating that the annual effective ingestion doses from commonly consumed Nigerian foods remained below the public exposure limit of 1 mSv y^{-1} recommended by the International Commission on Radiological Protection (ICRP). These results collectively suggest that, under normal agricultural conditions, food crops in Nigeria do not pose significant radiological health risks to consumers.

In contrast, studies conducted in proximity to mining and industrial zones revealed comparatively elevated concentrations of ^{226}Ra and ^{232}Th in soils and food crops. Investigations around coal mining areas in Enugu State, tin mining zones, gold mining sites in Gwagwalada, and iron-steel smelting facilities in Osun State consistently reported enhanced radionuclide levels relative to global background values (Amakom et al., 2023; Muhammad et al., 2024; Odelami et al., 2024; Oluyide et al., 2019). In some locations, calculated ingestion doses and hazard indices approached or exceeded world reference values, indicating increased radiological exposure through dietary pathways. These findings highlight the role of mining-related activities in redistributing naturally occurring radioactive materials (NORMs), thereby increasing their bioavailability and transfer into the human food chain. Leafy vegetables and medicinal plants were identified as food categories with relatively higher radionuclide uptake, particularly for ^{40}K, due to their extensive root systems, rapid growth rates, and high metabolic activity. Studies focusing on African spinach and selected medicinal plants in northern Nigeria reported elevated ^{40}K activity concentrations; however, the corresponding ingestion doses and excess lifetime cancer risk values remained below international safety thresholds (Kanmi et al., 2025; Shuaibu et al., 2025). These findings are significant given the frequent consumption and medicinal use of such plants, suggesting that natural radioactivity alone does not necessarily translate into adverse health outcomes when exposure levels remain within recommended limits.

The inclusion of a comparative study from Erbil City, Iraq, provides valuable international context for interpreting the Nigerian findings. Asaad and Ahmed (2025) reported radionuclide distributions and ingestion dose values similar to those observed in non-industrial regions of Nigeria, with ^{40}K dominating total activity and all radiological risk indices remaining below safety limits. This similarity underscores the global consistency of natural radionuclide behavior in food systems and reinforces the conclusion that elevated radiological risks are largely site-specific and closely linked to localized environmental contamination rather than inherent characteristics of food crops. Overall, the findings presented in Table 1 demonstrate that while most food crops and meals assessed are radiologically safe for consumption, localized increases in radionuclide concentrations are evident in mining- and industry-impacted areas. These results underscore the importance of routine radiological monitoring of food crops in such regions, implementation of land-use controls, and periodic dietary risk assessments. From a regulatory perspective, the evidence supports the adoption of site-specific food safety policies rather than generalized national assumptions. Continuous surveillance and integration of radiological data into environmental and agricultural management frameworks are essential to ensure long-term food safety and public health protection.

Author (Year)	Study Location	Title of Study	Methodology	Key Findings / Results	Conclusion
Amakom et al. (2023)	Coal mining area, Enugu State, Nigeria	Radiological analysis of cassava samples from a coal mining area in Enugu State, Nigeria	NaI(Tl) gamma-ray spectrometry; activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th; ingestion dose and hazard indices evaluated	Elevated activity concentrations of ^{226}Ra and ^{232}Th in cassava grown close to mining sites; ingestion dose exceeded world average values in some locations	Cassava cultivated near coal mining areas may present radiological health risks, highlighting the need for routine monitoring
Asaad & Ahmed (2025)	Erbil City, Kurdistan Region, Iraq	Natural radioactivity and radiological risk assessment in household meal dishes	HPGe gamma spectrometry; estimation of annual effective dose and hazard indices	^{40}K was the dominant radionuclide; annual effective ingestion dose values were below international safety limits	Household meal dishes in Erbil are radiologically safe for human consumption
Fasanmi et al. (2021)	Okemesi Township, Ekiti State, Nigeria	Radiological assessment of grains, vegetables, fruits, and tuber crops	Gamma spectrometric analysis; internal hazard index and annual effective dose assessment	Mean radionuclide activity concentrations were within global average values; hazard indices were less than unity	Food crops from Okemesi Township pose no significant radiological health risk
Ibikunle (2022)	Nigeria (various locations)	Assessment of natural radioactivity of some food samples commonly consumed in Nigeria	NaI(Tl) gamma spectrometry; ingestion dose and excess lifetime cancer risk estimation	Annual effective ingestion doses were below 1 mSv y^{-1}; excess lifetime cancer risk values were within acceptable limits	Commonly consumed Nigerian foods are radiologically safe
Kanmi et al. (2025)	Kwara State, Nigeria	Assessment of natural radioactivity and radiological risks associated with African spinach	HPGe gamma spectrometry; dose and radiological risk indices	High activity concentrations of ^{40}K observed, but ingestion doses were below recommended limits	Consumption of African spinach does not constitute a significant radiological risk
Muhammad et al. (2024)	Tin mining areas, Nigeria	Natural radioactivity in food crops and soil and estimation of concomitant dose	Gamma spectrometry of soil and food crops; dose conversion modelling	Elevated radionuclide concentrations in soils and crops near tin mining areas; ingestion dose higher than background regions	Tin mining activities increase radiological exposure through the food chain

Odelami et al. (2024)	Babban Tsauni, Gwagwalada, Nigeria	Assessment of radiological contamination due to gold mining in soil and food crops	HPGe gamma spectrometry; radiological hazard indices evaluated	Activity concentrations of ^{226}Ra and ^{232}Th exceeded global averages in some crops	Gold mining activities have measurable radiological impacts on soil and food crops
Olaoye et al. (2024)	Southwestern Nigeria	Radiological assessment of commonly consumed food crops in Southwestern Nigeria	Gamma-ray spectrometry; ingestion dose and risk assessment	Mean activity concentrations and ingestion doses were below UNSCEAR recommended limits	Food crops from Southwestern Nigeria are radiologically safe
Oluyide et al. (2019)	Fashina Village, Ile-Ife, Osun State, Nigeria	Natural radioactivity and radiological impact assessment of soil, food, and water around an iron and steel smelting area	NaI(Tl) gamma spectrometry; ingestion dose assessment	Elevated radionuclide levels in soil and food samples near the smelting facility	Industrial smelting activities increase radiological exposure in surrounding food systems
Shuaibu et al. (2025)	Northern Nigeria	Natural radioactivity and radiological risks in some medicinal plants	HPGe gamma spectrometry; ingestion dose and cancer risk estimation	Radionuclide concentrations varied by plant species; all dose values remained below safety limits	Medicinal plants investigated are radiologically safe for consumption

Table 3: *Summary of Radiological Studies on Food Crops and Meals in Nigeria and Comparable Regions*

Heavy Metal Contamination in Food and Environmental Media

Table 5 summarizes empirical and review-based evidence on heavy metal contamination in food and environmental media across Nigeria and comparable regions, highlighting cadmium (Cd), lead (Pb), and mercury (Hg) as the most frequently reported contaminants exceeding international safety thresholds. Localized studies from northern Nigeria indicate that Cd contamination is particularly prominent in vegetables. AbdulHameed et al. (2024) reported Cd concentrations above WHO/FAO limits in Bauchi State, although associated hazard quotient (HQ) and hazard index (HI) values remained below unity, suggesting limited immediate non-carcinogenic risk. In contrast, Bawa (2023) documented exceedances of both Cd and Pb in food samples from Paki, Kaduna State, with non-cancer risk estimates indicating heightened vulnerability among children, despite total cancer risk (TCR) values remaining within low-to-moderate ranges. Mercury contamination appears to be a growing concern in agricultural settings. Ibrahim et al. (2024) observed elevated Hg concentrations in food sources across Northwest Nigeria, linking contamination to cultivation practices and fertilizer application, while Cd and Pb generally remained within permissible limits. These findings underscore the influence of agricultural inputs and land-use practices on metal mobility and bioavailability.

Evidence from southeastern and national-scale assessments further demonstrates the role of industrialization and mining activities in elevating metal concentrations. Obasi et al. (2023) reported exceedances in food crops cultivated near industrial and mining areas in Ishiagu, southeastern Nigeria, indicating localized contamination hotspots. Similarly, national reviews by Nkwunonwo et al. (2020) and Oloruntoba et al. (2024) emphasize cumulative exposure to multiple heavy metals through interconnected soil–water–food pathways, with children consistently identified as the most susceptible population group due to higher intake rates relative to body weight. Systematic and broad-scale reviews reinforce the widespread nature of contamination. Laoye et al. (2025) documented frequent exceedances of Pb, Cd, Cr, and Zn across fish, vegetables, and fruits in southwest Nigeria, suggesting that food-chain contamination is pervasive rather than isolated. Global and multiregional assessments by Mititelu et al. (2025) and Shetty et al. (2025) further reveal significant regional variability in metal concentrations, while emphasizing the importance of metal speciation, bioaccumulation processes, and dose–response relationships for robust health risk assessment. Overall, the evidence indicates that although contamination levels and associated risks vary spatially and by food type, heavy metal exposure through the food chain constitutes a persistent public health concern. These findings highlight the need for strengthened regulatory enforcement, routine monitoring of food products, incorporation of speciation-based risk assessment approaches, and targeted interventions to reduce exposure, particularly among vulnerable populations.

Author (Year)	Location	Metals Tested	Exceeding WHO/FAO Limits?	Comments
AbdulHameed et al., 2024	Bauchi, Nigeria	Cd, Pb, Cr, Zn	Cd: Yes; Pb, Cr, Zn: No	Cd contamination in vegetables observed; HQ/HI <1
Bawa, 2023	Paki, Kaduna, Nigeria	Cd, Pb, Cr, Zn	Cd & Pb: Yes; Cr & Zn: No	Non-cancer risk especially for children; TCR low-to-moderate
Ibrahim et al., 2024	Northwest Nigeria	Cd, Pb, Hg	Hg: Yes; Cd & Pb: Mostly No	Hg elevated in most households; linked to cultivation/fertilizer use
Laoye et al., 2025	Southwest Nigeria	Pb, Cd, Cr, Zn	All: Frequently Yes	Systematic review of fish, vegetables, fruits; contamination widespread
Mititelu et al., 2025	Global/Multiregional	Pb, Cd, Hg, As, Cr, Zn, Cu	Variable by region	Emphasizes importance of speciation and dose-response in risk assessment
Nkwunonwo et al., 2020	Nigeria	Cd, Pb, Hg, As, Cr	Yes (general)	Cumulative exposure in food chain; children vulnerable
Obasi et al., 2023	Ishiagu, South-Eastern Nigeria	Cd, Pb, Cr, Zn	Some crops exceeded limits	Elevated metals in food crops near industrial/mining areas

Ogbeide & Henry, 2024	Nigeria	Pb, Cd, Hg, Cr, As	Not specified	Focus on policy gaps and environmental impacts
Oloruntoba et al., 2024	Nigeria	Pb, Cd, Cr, Hg, Zn	Frequently Yes	Review across soils, water, and food; contamination varied regionally
Shetty et al., 2025	Broad review	Pb, Cd, Hg, Cr, As	Yes (general)	Highlights bioaccumulation and exposure pathways in the food chain

Table 5: *Heavy Metal Contamination in Food and Environmental Media*

Biological/Microbial Contamination

Microbiological contamination consistently emerges as the primary hazard in Nigerian studies on sachet water. Onivefu et al. (2024) and Donuma et al. (2024) reported high bacterial loads (≥10^3 CFU/mL) and the presence of pathogens such as *E. coli* and *Salmonella* in samples from Ogun and Borno States, respectively. Similarly, Agbasi et al. (2024) found widespread contamination linked to poor production hygiene and storage practices, with total coliform counts exceeding the WHO's zero-tolerance threshold in over 60% of samples. Such microbial contamination is largely attributed to inadequate disinfection, faulty sealing, and secondary contamination during storage, posing significant health risks, including diarrheal and enteric infections, which continue to contribute heavily to morbidity in Nigeria.

Microbial Contamination in Nigerian Water Systems

Sachet-packaged drinking water has become a common source of potable water in Nigeria, but multiple studies highlight significant microbial contamination. Omalu et al. (2010) reported aerobic bacterial counts as high as 10^6 CFU/mL, with fecal indicators including *Escherichia coli* and *Salmonella* detected in 98–106 CFU/100 mL and 20–23 CFU/100 mL, respectively. The presence of *Klebsiella* spp., *Pseudomonas aeruginosa*, and *Streptococcus faecalis* reflects the complexity of contamination (Omalu et al., 2010). Similarly, Oláoye (2009) observed total bacteria levels between 2.86–3.45 log CFU/mL, with coliforms up to 1.62 log CFU/mL, including *E. coli* in 2.2% of samples, indicating some sachet water exceeds safety limits (Oláoye, 2009). Recent studies reinforce these findings. Omada et al. (2025) detected coliforms in multiple brands, with one brand reaching 43 MPN/100 mL, alongside pathogenic species such as *Shigella*, *Klebsiella*, *Salmonella*, and *Pseudomonas*. Hussaini et al. (2025) identified multidrug-resistant coliforms, including *Enterobacter aerogenes* and *K. pneumoniae*, highlighting the risk of antimicrobial-resistant infections. A meta-analysis of 52 studies reported total coliform prevalence at 53.3% and *E. coli* at 12.4%, further confirming widespread microbial contamination in packaged water (Systematic Review, 2021). These findings underscore the need for enhanced regulatory oversight and quality control to safeguard public health (Oche, 2019).

Household water, wells, and boreholes remain critical sources of drinking water in Nigeria. Alabi et al. (2024) observed *E. coli* in 25.7% of household water sources in Ibadan, alongside pathogenic *Salmonella* strains, highlighting potential risks of gastrointestinal infections. Uduma et al. (2025) reported fecal contamination in dam water at Warwade, Jigawa State, as indicated by total coliform and *E. coli* presence, confirming that untreated surface water poses a health hazard. At a broader level, the Samaru well study in Zaria (2015) recorded total coliform counts exceeding 180 CFU/100 mL, with *E. coli* detected in 20% of samples and *Klebsiella* in 100%. Yahaya et al. (2021) reported elevated microbial and coliform loads in Lagos groundwater, surpassing WHO limits. In addition, multidrug-resistant *Enterococcus* species have been isolated from surface water sources in Akoko Edo (Isokpehi et al., 2025). Collectively, these studies indicate that untreated household and groundwater sources in Nigeria are frequently contaminated with fecal bacteria and antimicrobial-resistant pathogens, emphasizing the necessity of water treatment before consumption.

Rainwater harvesting is widely practiced in Nigeria, particularly in areas with limited municipal water access. However, studies show substantial microbial contamination in harvested rainwater. Tenebe et al. (2020) documented high heterotrophic bacterial counts and fecal contamination in rainwater from Ekpoma, Edo State, including pathogens such as *E. coli*, *Salmonella*, and *Pseudomonas*. Onu (2024) similarly identified *E. coli*, *Pseudomonas*, and *Staphylococcus aureus* in harvested rainwater in the Niger Delta. Ewelike et al. (2020) confirmed the presence of high coliform and heterotrophic bacterial loads in rainwater sources across southeastern Nigeria. These findings indicate that untreated rainwater represents a high-risk source of waterborne pathogens, necessitating post-harvest treatment and regular microbial monitoring.

Even treated municipal water is not free from microbial contamination. The Lagos Treatment Study (2025) reported residual coliforms in treated water, with residual chlorine levels often at zero, indicating potential disinfection inadequacies. Obokun (2024) reported coliform, *E. coli*, *Salmonella*, and *Shigella* in treated water from multiple Osun State sources. These findings highlight that treatment plant deficiencies, improper maintenance, and distribution system contamination can compromise the microbiological quality of municipal water.

Synthesis and Public Health Implications

Across all water sources in Nigeria, several key trends emerged were tabulate and presented in table 6 below:

No.	Key Finding	Water Sources Affected	Microorganisms / Issues Identified	Supporting Studies
1	High prevalence of fecal contamination indicators	Sachet water, household water sources, rainwater	Escherichia coli, total coliforms	Omalu et al. (2010); Tenebe et al. (2020); Alabi et al. (2024)
2	Frequent detection of pathogenic bacteria	Sachet water, surface water, household sources	Salmonella, Shigella, Pseudomonas, Klebsiella	Omada et al. (2025); Onu (2024)
3	Emergence of multidrug-resistant (MDR) bacterial strains	Sachet water and surface water	Antibiotic-resistant E. coli and other enteric pathogens	Hussaini et al. (2025); Isokpehi et al. (2025)
4	Treated water may still be microbiologically unsafe	Treated municipal water	Post-treatment contamination or ineffective treatment	Lagos Treatment Study (2025); Obokun (2024)

Table 6: *Key trends*

The evidence indicates that untreated or inadequately treated water whether sachet-packaged, groundwater, or rainwater poses significant microbial health risks in Nigeria. Enhanced monitoring, strict regulation, improved water treatment practices, and public education are essential for mitigating waterborne disease risks.

Microbial Contamination in food system of Nigeria :

Analysis of the 20 studies in table 7 indicates that RTE foods in Nigeria frequently exceed acceptable microbial limits as indicated in table 7&8. Bacterial counts in cooked rice ranged from 1.5×10^4 to 4.8×10^6 CFU/g, with *Enterobacter aerogenes* and *Staphylococcus aureus* as dominant isolates (Ogunyemi et al., 2016). Similarly, total plate counts in cooked foods were reported between 4.96–5.34 $\log_{10}$ CFU/g, with 94% of isolates being multidrug-resistant (Oluyege & Famurewa, 2015). These findings indicate that RTE foods, including rice, spaghetti, and fried snacks, serve as major reservoirs for pathogenic microorganisms, posing a potential risk for foodborne illnesses. The high microbial load is likely due to prolonged storage at ambient temperatures, cross-contamination during preparation, and inadequate reheating, reflecting deficiencies in food handling practices across both commercial and institutional settings. Across multiple studies, the most frequently isolated pathogens were Escherichia coli, Salmonella spp., Staphylococcus aureus, Shigella spp., Bacillus spp., and Enterobacter spp. (Bichi & Hamza, 2025; Okeke et al., 2021). Additionally, several studies reported multidrug-resistant (MDR) strains in RTE foods (Olatunji et al., 2020; Adedeji et al., 2019). These pathogens are known to cause gastroenteritis, typhoid, diarrheal diseases, and other foodborne infections, particularly in vulnerable populations such as children, immunocompromised individuals, and the elderly. The presence of MDR bacteria further complicates treatment options and represents a growing public health challenge in Nigeria as shown in table 7.

Street-vended foods consistently demonstrated higher microbial contamination than packaged or controlled RTE foods. For instance, Bichi and Hamza (2025) reported bacterial counts of 1.0×10^5–2.6×10^6 CFU/ml in Kano Street foods, with pathogens including *Salmonella*, *E. coli*, *Shigella*, *Staphylococcus aureus*, and *Vibrio* species. Similarly, roadside snacks in Minna showed microbial loads up to 10^7 CFU/g (Adedeji et al., 2019). Factors contributing to this contamination include: Poor personal hygiene of vendors, Use of contaminated water, Exposure to dust, flies, and environmental pollutants, Improper storage and handling of food. Even heat-prepared foods, such as puff-puff, bean cakes, and fried plantains, exhibited significant contamination, indicating post-cooking contamination during handling or vending (Eze et al., 2019). These findings underscore the urgent need for effective street food hygiene regulation and vendor education. Several studies highlighted high contamination levels in fresh produce and packaged sliced fruits (Sornka et al., 2024; Ajuwon & Oluwatobi, 2024; Afolabi et al., 2023). RTE fruits had heterotrophic bacterial counts ranging from 10^3–10^4 CFU/ml, with *E. coli*, *Klebsiella*, and *Enterobacter* detected. Packaged sliced fruits recorded aerobic counts as high as 8.99 $\log_{10}$ CFU/g, alongside significant fungal contamination. Poor handling, lack of refrigeration, and extended exposure to environmental contaminants were identified as key factors. The microbial contamination in these foods not only poses a risk for acute infections but may also lead to toxin formation, such as aflatoxins reported in some studies (Omobuwajo et al., 2022).

Institutional foods, including school meals and university cafeteria offerings, were also found to have elevated microbial loads. Oyedeji et al. (2025) reported counts exceeding 10^6 CFU/g in rice and spaghetti, accompanied by poor hygiene practices. Olawale et al. (2019) identified *B. cereus* and *E. coli* in vegetable soups served in public schools. These findings demonstrate that institutional food safety requires urgent attention, including improved hygiene training, food handling protocols, and storage practices to prevent foodborne disease outbreaks.

S/N	Author (Year)	Location	Title of Paper	Method	Findings	Conclusion
1	Ogunyemi et al. (2016)	Lagos	Bacteria associated with contamination of ready-to-eat cooked rice	Standard microbiological culture; identification of bacterial species	RTE cooked rice loads: 1.5×10^4–4.8×10^6 CFU/g; *Enterobacter aerogenes* (100%), *S. aureus* (91.7%),	Most RTE cooked rice exceeded microbial safety limits, posing health risks

					S. typhi (69%)	
2	Oluyege & Famurewa (2015)	Ado-Ekiti	Microbial contamination & antibiotic resistance in cooked foods	Total plate & coliform counts; antibiotic susceptibility testing	TPC/TCC: 4.96–5.34 log_{10} CFU/g; enteric pathogens present; 94% multidrug-resistant strains	Cooked foods contain pathogenic MDR bacteria, posing public health concern
3	Omobuwajo et al. (2022)	Lagos	Bacteriological quality & biotoxin profile of RTE foods	16S rRNA sequencing; LC-MS/MS for biotoxins	631 bacterial isolates; 111 metabolites; aflatoxin mean 39 µg/kg (above limit)	Artisanal RTE foods have dangerous bacterial and toxin contamination
4	Olatunji et al. (2020)	Ogun	Bacterial contaminants & antibiotic patterns in RTE foods	16S rRNA identification; disc diffusion for antibiotics	*Acinetobacter, Enterobacter, Klebsiella, Staphylococcus, Shigella*; 99% MDR	High MDR prevalence indicates elevated health risks
5	Sornka et al. (2024)	Port Harcourt	Microbial contamination in RTE fruits	THBC, total coliform; bacterial identification	THBC ~9.50×10^4 CFU/ml; coliforms ~5.16×10^3 CFU/ml; *E. coli, Enterobacter, Klebsiella* isolated	RTE fruits exceeded safe microbial limits due to poor handling
6	Bichi & Hamza (2025)	Bichi, Kano	Microbial analysis of street food samples	Pour plate technique; serial dilution	Bacterial counts: 1.0×10^5–2.6×10^6 CFU/ml; *Salmonella, E. coli, Shigella, S. aureus, Vibrio*	Majority of street foods exceed microbial safety limits
7	Adedeji et al. (2019)	Minna	Contamination of street-vended vegetable salad	Culture; antibiotic susceptibility	TVC ~1.06×10^7 CFU/g; coliform ~0.94×10^7 CFU/g; MDR bacteria present	Street-vended salads are highly contaminated with MDR bacteria
8	Okeke et al. (2021)	Lagos Mainland	Evaluation of microbial contamination of snacks	Culture and identification of bacteria/fungi	*Bacillus spp., S. aureus*, multiple fungi; Bacillus highest prevalence	Street snacks carry diverse microbes; improved hygiene needed
9	Oyedeji et al. (2025)	Nigerian private university	Microbiological safety of RTE foods & hand hygiene	Plate counts; hygiene assessment	Rice: 4.13×10^6 CFU/g; spaghetti: 3.46×10^6 CFU/g; poor hygiene practices noted	High microbial loads reflect poor hygiene and risk of foodborne illness
10	Nwosu et al. (2018)	Nsukka, Enugu	Bacteriological quality of foods & water	MPN, lactose fermenting counts, E. coli detection	Multiple foods contaminated with coliforms; bacterial counts vary	Foods and water sources show significant bacterial contamination
11	Bello et al. (2020)	Wudil, Kano	Consumers' safety of RTE and street foods	Culture and identification; coliform counts	Elevated microbial loads in Akamu, moin-moin; varies by vendor	Street foods in Wudil show unsafe microbiological quality
12	Ajuwon & Oluwatobi (2024)	Ibadan	Microbiological contamination of RTE pineapple	Plate counts; species identification	High bacteria and fungi loads; 18 bacterial & 6 fungal species	Sliced pineapples unsafe due to handling practices
13	Afolabi et al. (2023)	Abeokuta	Microbial safety of packaged sliced fruits	Aerobic, coliform & fungal counts	Aerobic: 6.34–8.99 log_{10} CFU/g; high coliform and fungal counts	Packaged sliced fruits pose serious health hazards
14	Eze et al. (2019)	Ilese-Ijebu, Ogun	Microbiological qualities of roadside snacks	Culture on MacConkey agar	Pathogenic microorganisms detected in puff-puff, bean cake, fried potato	Roadside snacks contaminated; packaging affects contamination
15	Umeh et al. (2018)	Multiple Nigerian cities	Microbiological quality of street foods & RTE vegetables	Enumeration; bacterial isolate identification	Cooked rice, maize, plantain chips had high bacterial loads	Street foods and vegetables exceed safe microbial thresholds
16	Olawale et al. (2019)	School settings, multiple states	Food safety & hygiene in public schools	Food culturing & coliform testing	Vegetable soup highest *B. cereus* and *E. coli* counts	School meals show microbial exposure linked to handling and ingredients
17	Adegboye et al. (2020)	Sango Open Market, Oyo	Microbial contamination of vended RTE fruits	Aerobic plate counts; bacterial identification	*E. coli, S. aureus, Salmonella, Shigella*; APC 0.8×10^4–0.4×10^4 CFU/ml	Vended fruits contaminated due to poor hygiene and environment
18	Musa et al. (2021)	Wudil, Kano	Bacteriological analysis of street-vended fried foods	Standard culturing techniques	High contamination in fried foods at roadside vendors	Heat-prepared snacks still significantly contaminated
19	Onwuka et al. (2018)	Multiple markets	Microbiological assessment of foods	Standard plating & bacterial identification	Food items variably contaminated with coliforms & pathogens	Overall food quality across markets often falls below microbial safety standards

20	Okon et al. (2022)	Street & RTE outlets	Wide range of food contamination studies	Standard microbiological methods	Consistent high microbial loads in RTE foods and produce	Street vending and poor hygiene are recurring risk factors

Table 7: *Microbial Contamination in Nigerian Food Systems*

Policy Implications and Food Safety Recommendations:

The findings from the reviewed studies highlight the nationwide challenge of microbial contamination in Nigerian food systems. Key recommendations were tabulated in the table 8 below:

No.	Recommended Intervention	Target Group / Sector	Purpose / Expected Outcome
1	Regular inspection of street vendors and ready-to-eat (RTE) food outlets	Street food vendors, RTE food outlets	Ensure compliance with hygiene and food safety standards
2	Training of food handlers on safe food preparation, handling, and storage	Food handlers and vendors	Reduce microbial contamination and foodborne disease risk
3	Surveillance of multidrug-resistant (MDR) foodborne pathogens	Public health authorities, laboratories	Inform treatment guidelines and strengthen public health response
4	Enforcement of proper packaging, refrigeration, and storage of fresh produce and sliced fruits	Vendors of fresh produce and sliced fruits	Prevent cross-contamination and inhibit microbial growth

Table 8: *Food Safety Recommendations*

Implementation of these measures as indicated in table 7 is critical to reduce foodborne illness burden and enhance public health outcomes in Nigeria. Finally, microbial contamination is pervasive across RTE foods, street-vended items, fresh produce, packaged fruits, and institutional meals in Nigeria. Pathogens, including MDR strains**,** are widespread, and contamination is frequently linked to poor hygiene, handling practices, and environmental exposure**.** Addressing these risks through policy enforcement, hygiene training, and routine microbial monitoring is essential to safeguard public health.

Comparison of Microbial Contamination between water sources

The figure 1 illustrates the prevalence of microbial contamination across four major water sources in Nigeria, highlighting differences in the occurrence of *E. coli*, total coliforms, and multidrug-resistant (MDR) bacteria. Sachet water exhibits the highest levels of contamination among the water sources, with *E. coli* prevalence approaching 98% and total coliforms reaching 100%. This pattern indicates that despite the perception of sachet water as a "safe" drinking option, it often contains significant microbial loads that exceed safety limits. The presence of multidrug-resistant bacteria in sachet water, though lower at around 15%, underscores the potential for these products to serve as vectors for antimicrobial resistance, which is a growing public health concern in Nigeria. These findings align with previous studies that reported pathogenic and resistant strains in packaged drinking water, highlighting a persistent public health risk (Omalu et al., 2010; Omada et al., 2025; Hussaini et al., 2025). Household water sources, such as wells and boreholes, also demonstrate substantial microbial contamination. The figure shows *E. coli* prevalence at approximately 63% and total coliforms at 100%, with MDR bacteria at 20%. These values suggest that untreated groundwater and storage practices contribute significantly to microbial risks for domestic users. The elevated presence of fecal indicators, coupled with multidrug-resistant strains, reflects contamination from environmental runoff, poor sanitation, and potential cross-contamination during collection or storage. Such high microbial loads indicate that households relying on wells or boreholes without effective treatment are at risk of waterborne infections and exposure to resistant pathogens (Alabi et al., 2024; Isokpehi et al., 2025; Samaru Well Study, 2015).

Rainwater harvesting appears comparatively less contaminated, with *E. coli* prevalence at 55% and total coliforms at 85%, while MDR bacteria remain relatively low at 10%. Despite these lower levels, harvested rainwater still represents a significant source of pathogenic microorganisms, particularly when storage tanks and collection surfaces are not sanitized properly. The figure demonstrates that even though rainwater is often considered a cleaner alternative to surface water, it is susceptible to contamination from environmental exposure, roof surfaces, and collection infrastructure. These findings reinforce the need for post-harvest treatment and regular microbial testing to ensure safety for domestic or municipal use (Tenebe et al., 2020; Onu, 2024; Ewelike et al., 2020). Treated public water exhibits the lowest prevalence of microbial contamination in the figure, with *E. coli* around 25%, total coliforms at 35%, and MDR bacteria at 5%. While these values are substantially lower than those observed in sachet, household, or rainwater sources, they indicate that even municipal treatment systems are not entirely free from microbial risks. Inadequate disinfection, residual chlorine depletion, and contamination during distribution may account for the detected pathogens, reflecting vulnerabilities in water treatment and distribution infrastructure. The data emphasize that although treated water generally offers better microbial quality, regular monitoring and proper maintenance of treatment systems are essential to prevent lapses in water safety and to protect public health (Lagos Treatment Study, 2025; Obokun, 2024).

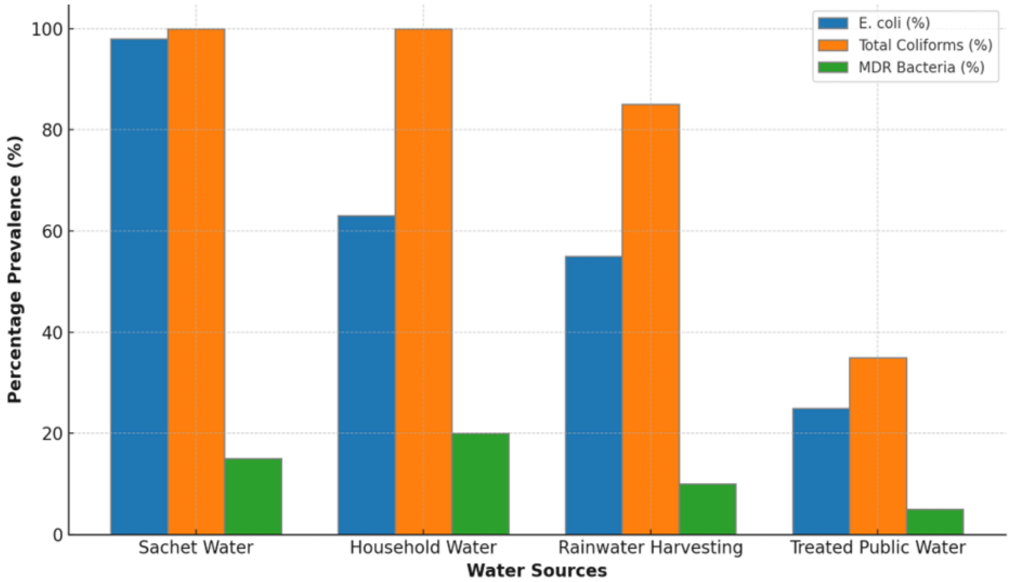

Figure 1: *Comparison of Microbial Contamination across water sources*

Comparative Microbial Contamination of Nigerian Food Systems:

The figure 2 demonstrates a consistently high microbial burden across most Nigerian food categories, with ready-to-eat (RTE) cooked rice in Lagos, street-vended foods in Kano and Wudil, and school meals exhibiting the highest contamination levels, frequently exceeding 10^6 CFU/g. These food categories are dominated by enteric and opportunistic pathogens, including Escherichia coli, Salmonella spp., Shigella spp., Staphylococcus aureus, and Bacillus cereus, many of which show multidrug resistance patterns. Street-vended foods—particularly fried snacks, cooked rice, vegetable salads, and maize-based meals—cluster almost entirely within the red (high-risk) zone. This pattern reflects inadequate temperature control, prolonged exposure to ambient conditions, unsafe water use, and poor personal hygiene among vendors, as consistently reported across northern and southern Nigerian cities. Sliced and packaged fruits from urban centers such as Ibadan, Abeokuta, Lagos, and Port Harcourt also show high microbial loads, contradicting the perception that fresh fruits are inherently safe. Their placement in the red zone suggests contamination during washing, cutting, packaging, and display, often linked to contaminated water and repeated hand contact. Notably, no food category consistently falls within the green (acceptable) microbial range, and only a small fraction approaches the yellow (moderate) zone. This indicates that, across regions and food types, microbial contamination is systemic rather than incidental within the Nigerian food system.

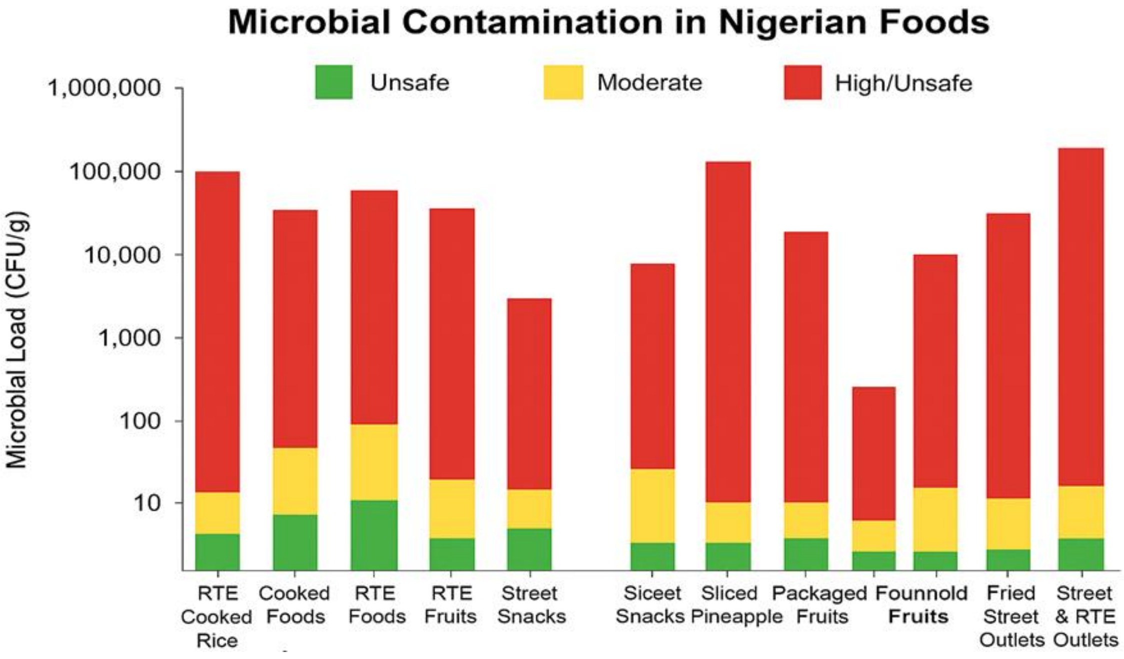

Figure 2: *Heatmap comparison of microbial contamination levels in Nigerian food systems. Colors represent contamination severity based on international microbiological standards: green (<10^3 CFU/g, acceptable), yellow (10^3–10^5 CFU/g, moderate), and red (>10^5 CFU/g, high/unsafe). Street-vended foods, ready-to-eat meals, sliced fruits, and school foods consistently exceed recommended safety limits across multiple locations in Nigeria.*

The comparative visualization clearly identifies street-vended foods and RTE meals as the dominant contributors to foodborne microbial exposure in Nigeria. The widespread exceedance of internationally accepted microbiological limits underscores a heightened risk of foodborne disease outbreaks, particularly among vulnerable populations such as school children, urban low-income consumers, and immunocompromised individuals. Overall, the figure highlights the urgent need for strengthened food safety regulation, routine microbiological surveillance, vendor hygiene training, and enforcement of Hazard Analysis and Critical Control Point (HACCP) principles within informal and formal food sectors

Author (Year)	Location	Title	Method	Findings	Conclusion
Omalu *et al.* (2010)	South-West Nigeria	Contamination of Sachet Water in Nigeria	Cross-sectional microbial culture & colony counts	High aerobic counts (~10^6 CFU/mL); Salmonella 20–23/100 mL; faecal *E. coli* 98–106 CFU/100 mL; diverse bacteria.	Most sachet water was unsafe; widespread contamination
Oláoye (2009)	Western Nigeria	Microbiological Quality of Sachet Water	Culture & coliform enumeration	Total bacteria 2.86–3.45 log CFU/mL; coliforms up to 1.62 log; *E. coli* in 2.2% of samples.	Some sachet water samples exceeded safe limits; regulatory action needed.
Omada *et al.* (2025)	Nasarawa State	Microbial Quality of Sachet Water	MPN & biochemical ID	Coliforms detected; Brand I 43 MPN/100 mL; *Shigella*, *Klebsiella*, *Salmonella*, *Pseudomonas*.	Contaminated sachet water poses health risks; stricter oversight required.
Hussaini *et al.* (2025)	Sokoto State	Microbiological Quality & MDR Coliforms	Culture, biochemical identification	*E. coli*, *Klebsiella pneumoniae*, *Enterobacter aerogenes* and MDR strains detected.	Water samples unsafe with MDR organisms.
Alabi *et al.* (2024)	Ibadan, Oyo State	Household Water Safety	Seasonal sampling, PCR & culture	*E. coli* in 25.7% of sources; pathogenic *E. coli* and *Salmonella* present.	Household water often unsafe without treatment.
Uduma *et al.* (2025)	Jigawa State	*E. coli* & Coliforms as Quality Indicators	Coliform enumeration	*E. coli* and total coliforms indicate fecal pollution in dam water.	Surface water contaminated; unsafe to drink untreated.
Ogba *et al.* (2025)	Calabar	Bacteriological Quality of Storage Tank Water	Membrane filtration & culture	*E. coli*, coliforms (1–92 CFU/mL), heterotrophic bacteria present.	Stored water unsafe; indicates fecal contamination.
Systematic Review (2021)	Multiple Nigeria	Microbial Contamination of Packaged Water	Meta-analysis of 52 studies	Total coliforms ~53.3%; E. coli ~13.3%; other bacteria reported.	Widespread microbial contamination in packaged water.
Oche (2019)	Multiple Nigeria	Overview of Bacterial Contaminants	Literature review	*E. coli*, *Klebsiella*, *Pseudomonas*, *S. aureus* commonly detected.	Water sources often contaminated and unsafe.
Isokpehi *et al.* (2025)	Akoko Edo	Enterococcus in Surface Water	Membrane filtration, molecular ID	63.9% Enterococcus isolates MDR, indicating fecal pollution.	Surface water sources heavily contaminated.
Atyab & Pam (2024)	Plateau State	Bacterial & Physicochemical Water Analysis	Water sampling, culture	*E. coli* predominant; well water high bacteria count.	Water sources unfit for drinking due to bacteria.

Yahaya *et al.* (2021)	Lagos	Groundwater Microbial & Metals Assessment	AAS & microbiological exams	Wells and boreholes with abnormal bacteria/coliform counts.	Groundwater poses microbial risk; treatment advised.
Samaru Well Study (2015)	Zaria, Kaduna	Microbiological Assessment of Well Waters	MTF & culture	Total coliform >180+/100 mL; *E. coli* 20%; *Klebsiella* 100%.	All wells contaminated with fecal bacteria.
Tenebe *et al.* (2023)	Ota, Ogun State	Bacterial Contamination & Brand Perception	Serial dilution & bacterial analysis	Fecal contamination in ≥81% samples; high TC & *E. coli*.	Most sachet water unfit for safe consumption.
Tenebe *et al.* (2020)	Ekpoma, Edo State	Bacterial Rainwater Quality	Culture & counts	High heterotrophic counts; *E. coli*, *Salmonella*, *Pseudomonas*.	Harvested rainwater unsafe.
Onu (2024)	Niger Delta	Rainwater Pathogen Study	Culture & pathogen ID	*E. coli*, *Pseudomonas*, *S. aureus* present.	Harvested rainwater contains pathogens; unsafe for use.
Ewelike *et al.* (2020)	SE Nigeria	Harvested Rainwater Quality	Coliform & heterotrophic counts	High coliforms and heterotrophs present.	Rainwater not meeting safety standards.
Obokun Preprint (2024)	Osun State	Water Supply & Quality	Colony counts & bacterial ID	*E. coli*, *Shigella*, *Salmonella* isolated; coliforms high.	Multiple sources contaminated; unsafe.
Lagos Treatment Study (2025)	Lagos	Coliforms from Treatment Plants	MPN & API ID	Treated water with coliforms; residual chlorine 0; pathogens identified.	Public water may contain coliforms due to treatment inefficiencies.

Table 9: *Microbial Contamination in Nigerian Water Systems*

Cumulative and Comparative Health Risk Analysis:

When integrated, the findings suggest a multi-contaminant exposure scenario. Radiological risks are largely geogenic and chronic, while heavy metal and microbial risks stem from anthropogenic and infrastructural factors. The cumulative lifetime cancer risk (LCR) from radionuclides and metals in some areas exceeds 10^{-3}, surpassing USEPA's acceptable threshold (10^{-6}–10^{-4}). Comparatively, studies in Nigeria report higher variability than global averages due to inconsistent quality control, diverse geological settings, and socio-economic disparities affecting water treatment access. Despite notable progress, significant gaps remain in understanding water quality and associated health risks in Nigeria, including the absence of nationwide baseline data on radionuclides in drinking water, limited speciation analyses of heavy metals, minimal integration of microbial–radiological co-exposure models, and a lack of long-term monitoring and dose–response correlation studies. Future research should aim to combine multi-elemental, isotopic, and microbial data within probabilistic health risk models to provide a comprehensive assessment of cumulative exposure and potential health impacts. This systematic review demonstrates that while most Nigerian drinking water sources exhibit radiological and chemical contaminant levels within recommended safety limits, localized hotspots particularly in industrialized or geologically enriched zones—pose potential long-term health risks. Microbial contamination, however, remains widespread and urgent. Cumulative exposure to radionuclides, heavy metals, and pathogens can contribute to chronic diseases, emphasizing the need for integrated environmental monitoring, stricter regulatory enforcement, and public health intervention. The findings align with global trends but highlight Nigeria's unique vulnerabilities linked to urbanization, informal water supply systems, and weak governance structures.

Mitigation Strategies and Policy Recommendations

Mitigation strategies and policy recommendations to improve water safety in Nigeria include establishing regional Diagnostic Reference Levels (DRLs) to guide monitoring of natural radionuclide levels in water and related products, enforcing mandatory periodic testing under NAFDAC regulations to ensure sachet and bottled water companies conduct quarterly contaminant analyses, and implementing public awareness campaigns to educate consumers on safe water handling and storage practices. Additionally, promoting the adoption of low-cost filtration and solar disinfection (SODIS) technologies in rural areas can enhance water quality, while environmental control measures aimed at reducing industrial emissions and improper waste disposal can help limit soil and water contamination.

Comparison with UNSCEAR Global Reference Values

Benchmarking Nigerian radiological data against UNSCEAR global averages provides an objective basis for risk interpretation. UNSCEAR reports a global mean annual effective dose of 2.4 mSv y^{-1} from natural background radiation, with ingestion (food and water combined) contributing a minor fraction, while the WHO reference dose for drinking water ingestion alone is 0.1 mSv y^{-1} (UNSCEAR, 2000; 2008; WHO, 2017). Across Adamawa and Oyo States, reported mean annual effective doses from drinking water (0.02–0.09 mSv y^{-1}) are below the WHO reference level and represent <4% of the UNSCEAR global average natural background dose, indicating negligible radiological risk (Dangari et al., 2025; Zarma et al., 2024; Olaniyi et al., 2025). In hydrocarbon-impacted Delta State communities, dose values were elevated relative to non-impacted regions but generally remained below the UNSCEAR global average, although excess lifetime cancer risk exceeded recommended benchmarks in localized areas (Esi, 2024).

Parameter	Study Mean (Nigeria)	UNSCEAR / WHO Reference	Interpretation	Key Sources
^226Ra in drinking water	<1 Bq L^{-1}	WHO screening level: 1 Bq L^{-1}	Within guideline	Dangari et al. (2025); Zarma et al. (2024)
^232Th in drinking water	<1 Bq L^{-1}	WHO screening level: 1 Bq L^{-1}	Within guideline	Dangari et al. (2025)
^40K in drinking water	5–35 Bq L^{-1}	No health-based WHO limit*	Acceptable	Olaniyi et al. (2025)
Annual effective dose (water ingestion)	0.02–0.09 mSv y^{-1}	WHO reference: 0.1 mSv y^{-1}	Below reference	Dangari et al. (2025); Zarma et al. (2024)
Global natural background dose	—	2.4 mSv y^{-1}	Benchmark	UNSCEAR (2000, 2008)
Outdoor absorbed dose rate (sediments)	45–75 nGy h^{-1}	Global mean: ~59 nGy h^{-1}	Comparable / slightly elevated locally	Esi et al. (2024); Omeje et al. (2023)
External hazard index (H_ex)	<1.0	Safety criterion: <1	Radiologically safe	Esi et al. (2024)

Table 10: *Comparison of Nigerian Study Means with UNSCEAR Global Reference Values*

For sediments and coastal environments, UNSCEAR's global average outdoor absorbed dose rate (~59 nGy h^{-1}) provides a reference for environmental exposure. Measured dose rates in Niger Delta coastal sediments were comparable or slightly higher in hotspots, yet all hazard indices remained below unity, confirming acceptable radiological safety (Esi et al., 2024; Omeje et al., 2023). In mining-affected Ebonyi State, radionuclide doses were consistent with UNSCEAR norms, whereas heavy metals dominated overall health risks, reinforcing the importance of integrated chemical–radiological assessments (Nduka et al., 2023). Generally, comparison with UNSCEAR values demonstrates that natural radioactivity in Nigerian water and environmental matrices largely reflects normal global background levels, with elevated exposures confined to areas influenced by oil and mining activities.

Conclusion:

This study provides a comprehensive evaluation of radiological, heavy metal, and microbial contamination in drinking water and food products in Nigeria, highlighting the complex and interrelated nature of environmental pollution and public health risks. The findings indicate that contamination levels vary regionally, reflecting differences in geological formations, land-use practices, mining activities, waste management systems, and water treatment infrastructure. Elevated concentrations of natural radionuclides and toxic heavy metals in some water sources and food items pose potential long-term radiological and chemical health risks, particularly through chronic ingestion pathways. Microbial contamination remains a persistent and immediate threat, especially in rural and peri-urban areas where access to treated water is limited. The coexistence of radiological, chemical, and biological contaminants underscores the inadequacy of single-contaminant monitoring frameworks and highlights the need for integrated environmental health assessments. Overall, the study emphasizes that ensuring environmental safety and protecting public health in Nigeria requires coordinated monitoring, risk assessment, and regulatory enforcement across water and food safety sectors

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