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IN-SITU RADIOMETRIC SURVEY OF DUMPSITES AT OKITIPUPA MAIN MARKET, ONDO STATE, NIGERIA

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Abstract

This study assessed radiological risks from gamma radiation exposure at three active dumpsites in Okitipupa Main Market, Ondo State, Nigeria. Using an in-situ method with a calibrated handheld detector and GPS mapping, ambient dose rates were measured to estimate activity concentrations and radiological hazard indices such as Annual Effective Dose Equivalent (AEDE) and Excess Lifetime Cancer Risk (ELCR). Results showed site-specific variations: Dumpsite A had the highest mean dose rate (0.192 μSv/h) and activity concentration (0.768 Bq/m³), followed by Dumpsite B (0.172 μSv/h, 0.689 Bq/m³), while Dumpsite C recorded the lowest values (0.159 μSv/h, 0.635 Bq/m³). All AEDE and ELCR values remained below international safety limits. Although the results show that radiation levels are within permissible limits, ongoing observation is required because of possible alterations brought on by trash buildup or illegal dumping. The study underscores the importance of continuous radiological monitoring and recommends implementing stricter waste management policies and public health safeguards to prevent future radiation risks linked to unregulated dumping and evolving waste composition.

Keywords: Dosimetry, Environmental monitoring, Exposure, Radiation, Waste dumpsites.

Introduction

Environmental contamination by naturally occurring radioactive materials (NORMs) has emerged as a global concern due to its implications for public health and ecological integrity (UNSCEAR, 2000). These materials, including uranium-238 (^{238}U), thorium-232 (^{232}Th), and potassium-40 (^{40}K), are naturally present in the Earth's crust, but anthropogenic activities such as mining, industrialization, and improper waste disposal can elevate their concentrations in localized environments (IAEA, 2003). In developing countries like Nigeria, ineffective waste management has led to the proliferation of open-air dumpsites that often receive a heterogeneous mix of domestic, electronic, industrial, and construction waste (Ezemonye et al., 2020). These waste streams may contain radionuclide-bearing materials, which, over time, can leach into the environment and increase radiation exposure to nearby populations. The decomposition and weathering of radioactive waste materials in open dumpsites release radionuclides into surrounding soils and air, potentially raising ambient radiation levels (Jibiri & Farai, 1998; Ilori et al., 2025). Human exposure to ionizing radiation from these sites may occur through external irradiation, inhalation of contaminated dust, or ingesting radionuclide-contaminated water and food. Long-term exposure to elevated radiation levels, even at low doses, is associated with increased risks of cancer and other health disorders (UNSCEAR, 2000; IAEA, 2003).

Radiometric surveys, particularly in-situ gamma spectrometry, and ambient dose rate measurements, offer efficient and non-destructive means of assessing environmental radiation. These techniques provide real-time data, facilitate the identification of radiological hotspots, and support public health decision-making (Garba et al., 2023). Several studies have investigated radiation levels around municipal dumpsites in Nigeria. Such studies include that of Odunaike et al. (2008), which recorded ambient dose rates between 0.092 and 0.123 μSv/h in Ibadan, while Faweya et al. (2019) reported values up to 0.167 μSv/h in Akure, suggesting that dumpsites can be significant contributors to localized radiation exposure.

Despite such findings, radiological data remain scarce for many semi-urban areas in Nigeria. Okitipupa, a growing commercial center in Ondo State, lacks documented assessments of radiation levels in its primary waste disposal sites. There is currently no published radiometric data for Okitipupa, making it impossible to evaluate whether the radiation exposure levels experienced by its population fall within safe limits or pose a significant health risk. The Okitipupa Main Market, surrounded by dense human activity, is a focal point for informal waste dumping. However, no systematic radiometric evaluation has been conducted to determine the potential health risks of residents, traders, and waste handlers.

This study addresses this gap by performing an in-situ radiometric survey of the dumpsite at Okitipupa Main Market. By measuring ambient gamma radiation levels, converting these to activity concentrations, and comparing them with international safety standards, the study aims to evaluate potential radiological risks to the local population. It contributes essential baseline data for environmental monitoring, supports evidence-based public health interventions, and adds to the limited but growing body of knowledge on environmental radioactivity in southwestern Nigeria. The findings will inform waste management strategies and promote radiation safety in similar urban contexts.

Materials and Methods

Description of the Study Area

Okitipupa's main market is in Okitipupa, a local government area in Ondo State, southwestern Nigeria. Geographically, the town lies between latitudes 6°30′ and 6°45′ N and longitudes 4°45′ and 5°00′ E, with an average elevation of 100–150 meters above sea level (Omogunloye *et al.*, 2022). The market is a central hub for commerce, drawing traders and consumers from surrounding rural and semi-urban communities to exchange agricultural produce, manufactured goods, and household items. Figure 1 shows a map of Ondo State, highlighting Okitipupa, the study area.

The area experiences a tropical rainforest climate, characterized by two distinct seasons: the rainy season (April to October) and the dry season (November to March), with annual rainfall averaging around 2000 mm and mean temperatures ranging from 25°C to 30°C (NIMET, 2020). High rainfall promotes soil leaching and affects waste decomposition processes, complicating environmental waste management in the region.

The market is densely populated and lacks a formal waste segregation system. Consequently, several unregulated dumpsites have emerged where domestic, agricultural, and commercial wastes are indiscriminately disposed of. These wastes include plastics, food residues, electronic components, and construction debris, some of which may contain naturally occurring radioactive materials (NORMs). The proximity of these dumpsites to food vendors and pedestrian pathways raises significant public health and environmental concerns.

The area's soil is predominantly sandy loam, underlain by sedimentary rock formations of the Dahomey Basin. This geological formation contains moderate levels of naturally occurring radionuclides, including ^{238}U, ^{232}Th, and ^{40}K (Ogala *et al.*, 2019). Combining natural geology and human activities such as open dumping and informal recycling may elevate radiation levels in localized zones.

Additionally, the market's spatial layout, characterized by narrow walkways, densely clustered stalls, and limited drainage infrastructure, restricts the natural dispersion of waste, promoting the accumulation of potentially hazardous substances in confined areas. These conditions make Okitipupa Main Market a strategic site for an in-situ radiometric survey to evaluate background gamma radiation and assess potential public exposure.

Figure 1: Map of Ondo State, highlighting Okitipupa, the study area.

Data Collection

This study employed an in-situ approach to measure ambient gamma radiation levels directly at selected dumpsites within the Okitipupa Main Market. This method allows for real-time, location-specific data acquisition without disturbing the natural environment and is widely recognized for its reliability in assessing environmental radiation exposure (IAEA, 2003).

Three active dumpsites within the market were selected for detailed investigation. At each site, six sampling points were established, resulting in a total of eighteen sampling locations. These points were strategically chosen based on key factors such as waste density and heterogeneity, accessibility for safe equipment handling, and the level of human activity, which influences potential exposure risks. This layout ensured comprehensive spatial coverage of each dumpsite.

Before the primary survey, a reconnaissance study was conducted to identify representative and accessible sampling points. At each location, ambient gamma dose rates were measured using a calibrated handheld gamma radiation detector, positioned approximately one meter above ground level, in line with standard practice to simulate human breathing zone exposure (UNSCEAR, 2000).

Table 1: Sampling locations and the criteria used for their selection.

Sampling Points	No. of Sampling	Justification for Dumpsite Selection
Dumpsite A	6	High waste density; frequent human interaction.
Dumpsite B	6	Mixed waste composition; moderate foot traffic.
Dumpsite C	6	Proximity to residential and trading areas; accessible terrain.

To support spatial referencing, GPS coordinates were recorded for each sampling point. The detector was allowed to stabilize for approximately 60 seconds before recording readings to ensure accuracy. Simultaneously, field observations were documented, including the type of waste present, surrounding environmental conditions, and any visible signs of degradation or pollution. Photographs of each sampling point were also taken to provide visual context for subsequent data interpretation.

All measurements were conducted during daylight hours to ensure visibility and operational safety. Regular checks confirmed that the detector remained properly calibrated throughout the fieldwork. The data collected were then systematically organized and prepared for detailed analysis.

Measurement Technique

The in-situ radiometric survey at the Okitipupa Main Market dumpsites was carried out using carefully selected instruments and procedures to ensure data accuracy and field safety. A GQ GMC-500 Geiger Counter (shown in Figure 2), which is a handheld gamma radiation detector fitted with a Geiger-Müller (GM) tube, was employed to measure ambient gamma dose rates expressed in micro-sieverts per hour (μSv/h). This device was calibrated in line with the manufacturer's guidelines and used at approximately one meter above the ground to reflect the typical human exposure height, consistent with recommendations by the

International Atomic Energy Agency (IAEA, 2003) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000).

Figure 2: GQ GMC-500 Geiger Counter used in the field survey.

A handheld GPS device was used to record the precise geographic coordinates at each sampling point to accurately determine the spatial distribution of radiation levels across the study area. This spatial referencing enabled a more straightforward interpretation of exposure variations within the market environment. During fieldwork, observations and measurements were carefully recorded using standardized data sheets that captured essential information such as radiation readings, measurement times, prevailing weather conditions, and descriptions of the immediate environment. Visual documentation was also done using a digital camera or smartphone to support the data with contextual images of each dumpsite. Throughout the field exercise, personal protective equipment, including gloves, face masks, and protective footwear, was worn to minimize health risks associated with exposure to hazardous waste materials. Upon completing the field survey, the collected data were systematically entered into a laptop using spreadsheet software, allowing for effective organization, processing, and preliminary statistical analysis. This integrated approach ensured the radiometric assessment was reliable and reproducible, contributing to a comprehensive evaluation of potential environmental radiation exposure in the study area.

Data Analysis Methods

The measured gamma dose rates obtained during the in-situ survey were compiled and organized for statistical and comparative analysis. Descriptive statistics, including mean, minimum, maximum, and standard deviation, were calculated using spreadsheet software to summarize the radiation levels across all sampled locations.

To assess potential health risks and environmental implications, the recorded dose rates (in μSv/h) were evaluated against international safety standards recommended by bodies such as the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) and the International Commission on Radiological Protection (ICRP, 2007). The spatial distribution of the data was further analyzed using geographic coordinates obtained from GPS measurements, facilitating the identification of elevated radiation zones within the dumpsites.

For a more direct understanding of environmental contamination, measured dose rates were converted into corresponding activity concentrations in air (Bq/m³) using an appropriate dose conversion factor (C_f), as described below.

Conversion of Count Rates to Activity Concentrations

The conversion of measured ambient gamma dose rates into activity concentrations was carried out to estimate the presence of radionuclides in the surrounding air. This transformation is crucial for assessing inhalation exposure risks and aligning environmental measurements with regulatory benchmarks.

The activity concentration (A, in Bq/m³) was calculated using the equation (IAEA, 2003):

$$A = \frac{D}{C_f} \quad (1)$$

D represents the ambient dose rate (μSv/h), and C_f is the dose conversion factor, expressed in μSv/h per Bq/m³. The C_f applied reflects standard estimates based on average gamma energy emissions from naturally occurring radionuclides commonly found in waste sites. For general environmental gamma exposure assessments, an average conversion factor of approximately 0.25 μSv/h per Bq/m³ is used as an estimate (Abodunrin, 2016).

Calculation of Radiological Hazard Indices

Key radiological hazard indices were calculated to evaluate the potential health implications of exposure to natural background radiation at the dumpsites. These indices provide insight into long-term exposure risks and assist in comparing the measured values against international safety standards.

Annual Effective Dose Equivalent (AEDE)

The AEDE in mSv/yr estimates the annual radiation dose that individuals may receive due to environmental exposure. It incorporates factors such as time spent outdoors and the biological effectiveness of ionizing radiation. The AEDE (in mSv/year) was calculated using the expression (Bodunrin *et al.*, 2021):

$$AEDE = D \times T \times Q \times 10^{-6} \quad (2)$$

whereD is the absorbed dose rate in nGy/h, *T* is the time conversion factor (8760 hours/year), Q is the dose conversion coefficient (0.7 Sv/Gy), and 10^{-6} is a conversion factor from nano- to millisieverts. This calculation directly compares with the global average outdoor exposure limit of 0.07 mSv/year UNSCEAR (2000) recommended.

Excess Lifetime Cancer Risk (ELCR)

The ELCR quantifies the probability of an individual developing cancer over a lifetime due to exposure to ionizing radiation. It was determined based on the AEDE using the following relation (Ugbede & Benson, 2018):

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

where AEDE is the annual effective dose equivalent (mSv/year), DL is the average duration of life expectancy (assumed as 70 years), and RF is the risk factor per sievert (0.05 Sv^{-1}) as recommended by ICRP (1991).

Results and Discussion

Measured Radiation Levels

Ambient gamma radiation dose rates and corresponding activity concentrations varied across the three selected dumpsites in Okitipupa Main Market, reflecting site-specific characteristics and waste management conditions. Using an in-situ radiometric survey method, this study measured ambient gamma radiation levels at three active dumpsites (A, B, and C) within the Okitipupa Main Market. The results, presented as dose rates (D, in μSv/h) and the corresponding activity concentrations (A, in Bq/m³), reveal variations in radiation levels across the sites, as summarized in Table 2.

Dumpsite A, marked by high waste density and frequent human presence, recorded the highest average dose rate of 0.192 μSv/h and an activity concentration of 0.768 Bq/m³. The elevated values are likely influenced by the volume and nature of waste and continuous human activity that may enhance radionuclide dispersion and surface

Table 2: Measured Ambient Dose Rates (μSv/h), Estimated Activity Concentrations (Bq/m³), and the Radiological Risks at Selected Dumpsites in Okitipupa Main Market.

Samplin Dumpsit	Samplin Points	D (μSv/h	A (Bq/m³	AEDE (mSv/y	ELCR
A	A1	0.187	0.748	0.00115	0.0040
	A2	0.204	0.816	0.00125	0.0044
	A3	0.190	0.760	0.00117	0.0041
	A4	0.182	0.728	0.00112	0.0039
	A5	0.200	0.800	0.00123	0.0043
	A6	0.189	0.756	0.00116	0.0041
Mean		**0.192**	**0.768**	**0.0011**	**0.0041**
Std. Dev		**0.008**	**0.033**	**0.0000**	**0.000**
B	B1	0.165	0.660	0.00101	0.0035
	B2	0.177	0.708	0.00109	0.0038
	B3	0.169	0.676	0.00104	0.0036
	B4	0.170	0.680	0.00104	0.0036
	B5	0.180	0.720	0.00110	0.0039
	B6	0.173	0.692	0.00106	0.0037
Mean		**0.172**	**0.689**	**0.0010**	**0.0037**
Std. Dev		**0.006**	**0.022**	**0.0000**	**0.0001**
C	C1	0.157	0.628	0.00096	0.0034
	C2	0.162	0.648	0.00099	0.0035
	C3	0.160	0.640	0.00098	0.0034
	C4	0.159	0.636	0.00097	0.0034
	C5	0.155	0.620	0.00095	0.0033
	C6	0.160	0.640	0.00098	0.0034
Mean		**0.159**	**0.635**	**0.0009**	**0.0034**
Std. Dev		**0.002**	**0.010**	**0.0000**	**0.0001**

exposure. Dumpsite B, with a mixture of waste types and moderate human traffic, exhibited a slightly lower average dose rate of 0.172 μSv/h and an activity concentration of 0.689 Bq/m³. These intermediate readings may result from the diversity of discarded materials, which include sources of both natural and anthropogenic radionuclides. In contrast, Dumpsite C, situated close to residential and commercial areas but with less foot traffic and a more stable terrain, showed the lowest radiation values. The mean dose rate was 0.159 μSv/h, and the corresponding activity concentration was 0.635 Bq/m³. These lower levels suggest limited radionuclide content and minimal site disturbance. Significantly, the radiation measurements at all sites fall below the global safety threshold for public exposure. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) and the International Commission on Radiological Protection (ICRP, 1991) recommend a limit of 1.0 mSv/year for the general public, equivalent to about 0.114

µSv/h when averaged over continuous exposure. Although the measured rates are slightly above this hourly average, they are based on short-term field conditions and do not necessarily represent continuous exposure. The findings indicate that radiation levels across the studied dumpsites are within acceptable safety margins. However, periodic assessment remains essential to detect potential changes due to waste accumulation or unauthorized dumping of radioactive materials. Figure 3 is a comparative bar chart illustrating the mean external dose rates (µSv/h) and activity concentrations (Bq/m³) for each dumpsite (A, B, and C), with error bars showing standard deviation, which confirms the trend observed in the results, linking radiation levels to waste density and human activity.

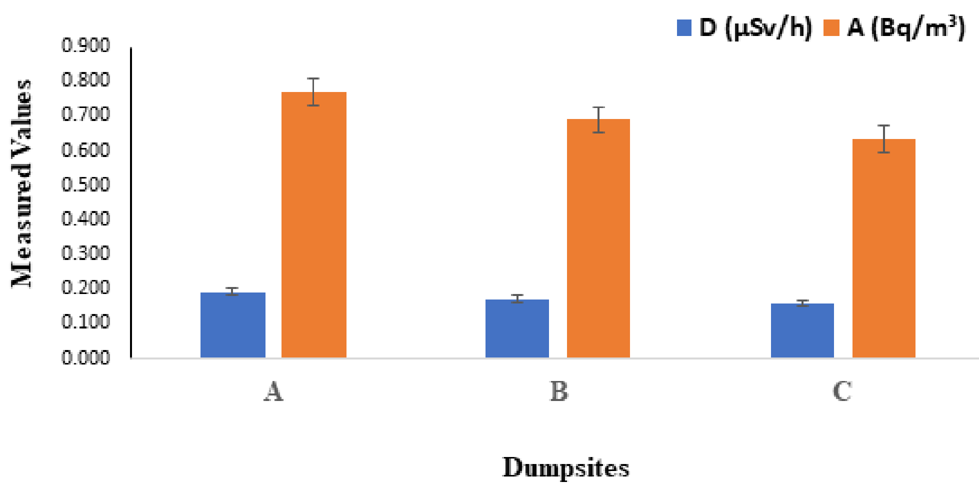

Fig 3: Comparison of Mean Radiation Levels and Activity Concentrations by Dumpsite.

Analysis of Radiological Indices

The analysis of radiological hazard indices across the three surveyed dumpsites within Okitipupa Main Market revealed variations in both the Annual Effective Dose Equivalent (AEDE) and Excess Lifetime Cancer Risk (ELCR), as shown in Table 2, reflecting differences in waste density, human activity, and proximity to residential or trading areas.

Dumpsite A recorded the highest AEDE and ELCR values. The AEDE ranged from 0.00112 to 0.00125 mSv/yr, with a mean of 0.00118 mSv/yr, while ELCR values ranged from 0.0039 to 0.0044 (mean: 0.0041). These elevated levels may be attributed to the site's high waste density, frequent human interaction, and accessibility—factors that likely contribute to increased accumulation and exposure to naturally occurring radioactive materials (NORMs).

Dumpsite B showed intermediate AEDE values between 0.00101 and 0.00110 mSv/yr (mean: 0.00106 mSv/yr), and ELCR ranged from 0.0035 to 0.0039 (mean: 0.0037). The moderate radiological profile may be linked to its mixed waste composition and average foot traffic, indicating some degree of exposure, though less pronounced than Dumpsite A.

Dumpsite C recorded the lowest exposure levels, with AEDE values between 0.00095 and 0.00099 mSv/yr (mean: 0.00097 mSv/yr) and a mean ELCR of 0.0034. These findings may be due to lower waste concentration and reduced human activity, though its closeness to residential areas underscores the need for continued monitoring.

All AEDE values remained well below the internationally recommended public dose limit of 1.0 mSv/yr, indicating no immediate radiological threat to market users. However, even low-level, long-term exposure may contribute incrementally to health risks, emphasizing the importance of regular assessments and public health vigilance.

While the current exposure levels are within global safety thresholds, site-specific factors such as waste type, usage pattern, and human interaction could affect future radiological risks. Continued environmental monitoring and effective waste management are essential to ensure public safety.

Comparison with Similar Studies

The results of this study were compared with findings from previous radiometric investigations conducted in similar waste environments across Nigeria and internationally, as shown in Table 3. The mean Annual Effective Dose Equivalent (AEDE) values from the Okitipupa dumpsites, ranging from 0.00097 to 0.00118 mSv/yr, fall within the same order of magnitude reported by Jwanbot et al. (2012) in their survey of Jos metropolis dumpsites, where AEDE values ranged between 0.00102 and 0.00129 mSv/yr. Similarly, Avwiri and Olatubosun (2014) found comparable dose equivalents in Port Harcourt's refuse dumps, highlighting the consistent nature of background gamma radiation in Nigerian waste disposal sites.

When assessed alongside Egbuchua & Bosah (2013), who recorded AEDE values of 0.00085–0.00115 mSv/yr in municipal waste dumpsites in the Niger Delta, the values from Okitipupa are slightly higher at Dumpsite A but generally remain within the safe threshold. This variation may be attributed to differences in waste composition, proximity to residential zones, and geological factors.

On a global scale, the values from this study are significantly lower than those reported in certain high-background radiation areas. Shuaibu et al. (2017) observed AEDE levels above 0.005 mSv/yr in Indian coastal regions affected by monazite-rich sands, underscoring the relatively low radiological risks of the Okitipupa market dumpsites.

The ELCR values in this study (0.0033–0.0041) are slightly elevated compared to the acceptable global benchmark of 0.00029 recommended by the USEPA (1987), yet similar values have been reported in related studies across Nigerian waste environments (Adefemi & Awokunmi, 2009; Ezemonye *et al.*, 2020), suggesting a need for broader public health dialogue concerning chronic low-dose exposure in informal waste management zones.

Overall, the findings corroborate existing literature, affirming that while the radiation exposure levels in such environments may not present acute health risks, continued monitoring and public education remain necessary to mitigate long-term radiological impacts.

Table 3: Comparison of Radiological Indices from This Study with Previous Studies.

Study Location	AEDE (mSv/yr)	ELCR	Reference	Remarks
Okitipupa Dumpsites (This Study)	0.00097 – 0.00118	0.0033 – 0.0041	Present Study	Within the UNSCEAR safe limit, slightly above the global ELCR benchmark

Jos Metropolis Dumpsites	0.00102 – 0.00129	–	Jwanbot et al. (2012)	Comparable AEDE range
Port Harcourt Refuse Dumps	~0.00120	–	Avwiri and Olatubosun (2014).	Similar exposure levels
Niger Delta Municipal Dumps	0.00085 – 0.00115	–	Egbuchua & Bosah (2013)	Slightly lower than Okitipupa; dependent on regional waste composition
High Background Area, India	>0.005	–	Shuaibu et al. (2017)	Significantly higher natural radiation source (monazite sands)
USEPA Global Benchmark	–	0.00029	USEPA (1987)	ELCR values in Okitipupa exceed this benchmark
Nigerian Waste Sites (General)	~0.001 – 0.0013	~0.003 – 0.004	Adefemi & Awokunmi (2009); Ezemonye et al. (2020)	Okitipupa values fall within the national range.

Conclusion

This study investigated gamma radiation levels at three active dumpsites in Okitipupa Main Market, Ondo State, Nigeria, using in-situ radiometric surveys in line with IAEA and UNSCEAR standards. Measurements taken across 18 points revealed spatial differences in radiation exposure, with Dumpsite A, marked by dense waste and high human activity, showing the highest dose rates and radionuclide concentrations. While all calculated radiological risk indicators remained within global safety limits, the elevated exposure at Dumpsite A raised public health concerns due to its proximity to vendors and pedestrian traffic. The study linked higher radiation levels to the nature of waste materials, especially electronic and construction debris, and emphasized the role of the region's geological setting in potentially increasing natural background radiation. It advocates for routine monitoring, waste segregation, public education, and policy reforms to manage radiation risks effectively. An integrated strategy combining scientific assessment, environmental governance, and community awareness is deemed essential for ensuring safety and promoting sustainable urban development.

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ASSESSMENT OF PHARMACEUTICAL RESIDUES IN SELECTED SURFACE WATERS IN IJEBU-ODE, NIGERIA USING SOLID PHASE EXTRACTION-HIGH PERFORMANCE LIQUID CHROMATOGRAPHY (SPE-HPLC)

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Abstract
The presence of pharmaceutical compounds (PCs) in the environment, especially in developed countries, has not only been ascertained, but their adverse impacts have been investigated and reported even at trace levels. However, there is a paucity of information on the occurrence patterns of these compounds in selected African environments like Nigeria. Hence, this study focused on the investigation of seven PCs in some surface waters within Ijebu-Ode, Ogun State, Nigeria, in five major rivers, namely Rivers Ona, Erinwe, Imagbon, Iweni, and Adamegi. These compounds include antibiotics- trimethoprim (TMP), sulfamethoxazole (SMZ), and ciprofloxacin (CIP); analgesics- paracetamol (PCM), diclofenac (DCF), and ibuprofen (IBU) and an antidiabetic- metformin (MET). The analyte PCs were monitored using a solid phase extraction- high-performance liquid chromatographic method (SPE-HPLC) which was developed and validated according to the International Conference on Harmonization guidelines. The highest levels of PCM (2.13 ± 0.28 μg/mL) and CIP (0.50 ± 0.07 μg/mL) were detected in the Erinwe River, while the highest concentrations of SMZ (2.25 ± 0.30 μg/mL) and TMP (0.35 ± 0.05 μg/mL) were detected in River Ona. Generally, the Σ PCs (μg/mL) in the rivers sampled are in the order SMZ (4.09) > PCM (3.01) > CIP (0.78) > DCF (0.56) > TMP (0.46) except for MET and IBU, which were not detectable in any of the rivers. Generally, the results obtained in this study are relatively high; hence, policies must be put in place to commence their removal from the environment.
Keywords: Pharmaceutical compounds, Surface waters, SPE-HPLC method, Environment, Nigeria.

Introduction

The contamination of the environment has been traced to the presence of specific compounds, such as polycyclic aromatic hydrocarbons (PAHs) (Finch and Stubblefield, 2019), pharmaceuticals, and personal care products (PPCPs) (Kümmerer, 2009; Omotola and Olatunji, 2020; Omotola et al., 2022), brominated flame retardants (BFRs) (Nakayama et al., 2019), poly- and perfluoroalkyl substances (PFASs), microplastics (Prata et al., 2018; Zhang, 2017) and other persistent organic pollutants (Prata et al., 2018; Zhang, 2017).