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ORIGINAL RESEARCH ARTICLE

Quality Assessment of Harvested Rain Water Collected From Corrugated Iron Rooftops in Mubi Metropolis, Adamawa State, Nigeria

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ABSTRACT

This study comprehensively evaluates the quality of harvested rainwater collected from corrugated iron rooftops in Arahan Kunu and Chandal within Mubi Metropolis, Adamawa State, Nigeria. Rapid urbanization and chronic municipal water supply deficits have forced these communities to rely heavily on harvested rooftop rainwater for daily domestic needs. Nine seasonal rainwater samples and corresponding ground-level controls were collected during May, July, and September to systematically assess the direct impact of catchment surfaces on water safety. Essential physicochemical parameters, including pH, temperature, dissolved oxygen, and biochemical oxygen demand, were measured alongside total coliform bacterial counts using standard laboratory protocols. Trace heavy metal concentrations, specifically zinc, lead, cadmium, nickel, manganese, and chromium, were carefully quantified using Atomic Absorption Spectrophotometry following a comprehensive microwave-assisted sample digestion method. The investigation focuses on characterizing localized chemical contamination pathways driven by atmospheric deposition, dry-season dust, animal droppings, and rooftop material leaching via accelerated corrosion. By modeling toxicological suitability and microbial risk profiles, this paper successfully establishes a critical baseline for domestic water safety. The ultimate goal is providing empirical data to guide localized first-flush diversion practices and essential public health interventions within water-scarce sub-Saharan semi-urban environment landscapes.

Introduction

Water is an essential natural resource required for human survival, environmental sustainability, and socioeconomic development. However, access to safe and reliable water remains a major challenge in many developing nations, particularly within sub-Saharan African rural and semi-urban communities where conventional municipal water supply systems are inadequate. Consequently, rainwater harvesting has emerged as a critical alternative source for

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domestic water supply in many regions (Terêncio et al., 2018).

Rainwater harvesting involves the collection and storage of runoff from rooftops or other designated catchment surfaces for domestic, agricultural, and environmental purposes. This practice has gained increasing global attention because it significantly reduces pressure on conventional groundwater resources and buffers water availability in water-scarce communities (Eludoyin et al., 2021). In many parts of Nigeria, harvested rainwater is routinely relied upon for drinking, cooking, washing, and other household activities due to chronic deficits in treated pipe-borne water infrastructure (Musa et al., 2017).

Although ambient rainwater is often considered relatively clean during atmospheric condensation, its final quality is heavily influenced by localized environmental factors. These include atmospheric deposition, rooftop material composition, dry-season dust accumulation, and animal droppings deposited on roof surfaces prior to precipitation events (De Buyck et al., 2021). Catchment surfaces are particularly critical because they can introduce chemical contaminants into the harvested supply through accelerated corrosion and leaching processes. Corrugated iron roofing sheets are widely utilized across Nigerian communities because of their affordability, durability, and commercial availability; however, they have been shown to leach trace metals into runoff during rainfall events (Mendez et al., 2011; Itodo et al., 2021).

The microbiological quality of harvested rainwater represents an equally pressing public health concern. Previous investigations have documented significant loads of total and fecal coliform bacteria in rooftop-harvested systems, primarily driven by the wash-off of environmental debris and avian or mammalian wastes deposited on rooftops (Ezemonye et al., 2016). Direct consumption of such contaminated water increases the morbidity of waterborne diseases and related gastrointestinal complications, especially in communities where the harvested rainwater is consumed raw without first-flush diversion or treatment (Gundry et al., 2012).

Beyond immediate microbial risks, the long-term ingestion of trace heavy metals poses severe health threats. Chronic exposure to elements like chromium, cadmium, lead, and nickel can induce progressive toxic effects, including nephrotoxicity, neurological disorders, hepatic damage, and elevated lifetime cancer risks (Ali et al., 2019). Therefore, precise quantitative monitoring of harvested rainwater parameters is essential to establish baseline safety profiles for domestic ingestion.

Despite the heavy reliance on corrugated iron rooftops for domestic water supply in Mubi Metropolis, sparse empirical data exists regarding the specific physicochemical interactions, microbiological safety, trace metal profiles, and associated health risk indices of harvested rainwater in this specific environment. This study was therefore conducted to comprehensively evaluate the quality of rainwater harvested from corrugated iron rooftops across selected communities (Arahan Kunu and Chandal) in Mubi, Adamawa State, Nigeria, and to model its toxicological suitability for direct domestic consumption.

Materials and Methods

Materials

All reagents and chemicals used in this study were of analytical grade. Nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) were used for sample digestion, while ultrapure water was used for dilution and rinsing of laboratory apparatus. Clean acid-washed plastic containers were used for sample collection to prevent contamination. Instruments used in the analysis included a calibrated pH meter,

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dissolved oxygen (DO) meter, biochemical oxygen demand (BOD) incubator, membrane filtration unit, and Atomic Absorption Spectrophotometer (AAS).

Study Area

The study was conducted in Mubi Metropolis, the second largest commercial town in Adamawa State, Nigeria. The metropolis covers an estimated land area of approximately 600 km² and lies about 260 km north of Yola, the state capital. Geographically, the metropolis is located between latitudes 10°05′ and 10°30′ N of the equator and between longitudes 13°12′ and13°19′ E of the Greenwich meridian (Yohanna et al., 2014).

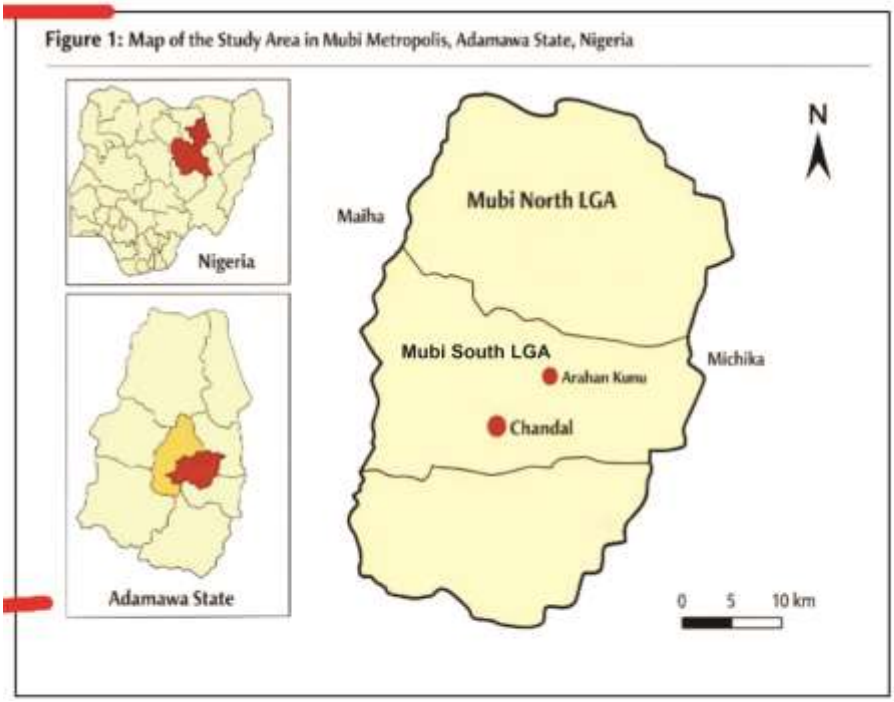

Figure 1: Map of the Study Area

Sample Collection and Preparation

Rainwater samples were collected from corrugated iron rooftops in selected residential buildings within Mubi Metropolis during the rainy season in May, July, and September. Three replicate samples were collected during each sampling period, resulting in a total of nine harvested rainwater samples.

Control samples of rainwater were collected at ground level in open spaces to minimize rooftop interference. These control samples were used to evaluate the influence of rooftop surfaces on rainwater quality.

Samples were collected from Arahan Kunu and Chandal, using clean plastic containers previously rinsed with nitric acid. Immediately after collection, samples were filtered through 0.45 µm membrane filters to remove suspended particles. The filtered samples were transported to the laboratory in ice-cooled containers and stored below 4°C prior to analysis

Digestion Procedure

Sample digestion was carried out using a microwave digestion method to ensure complete dissolution of heavy metals. A volume of 100 mL of each filtered rainwater sample was transferred into a microwave

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digestion vessel. Subsequently, 5 mL of concentrated nitric acid (HNO_3) and 2 mL of hydrogen peroxide (H_2O_2) were added.

The mixture was digested at 600 W for 10 minutes at 180°C. After digestion, the samples were allowed to cool to room temperature and diluted to a final volume of 50 mL using ultrapure water.

Heavy Metal Analysis

The concentrations of zinc (Zn), lead (Pb), cadmium (Cd), nickel (Ni), manganese (Mn), and chromium (Cr) were determined using Atomic Absorption Spectrophotometry (AAS) following the method described by Alexander et al. with slight modifications.

The digested samples were analyzed under the following operating conditions:

- Wavelengths (nm): Pb (217.0), Cd (228.8), Cr (357.9)
- Slit width: 0.5 nm
- Lamp current: 10 mA
- Flame type: Air–acetylene

An aliquot of each digested sample was aspirated into the AAS instrument and absorbance readings were recorded. Quality assurance procedures included reagent blanks, duplicate samples, certified reference materials, and spiked samples to ensure analytical accuracy and precision.

Determination of Physicochemical Parameters

Physicochemical parameters including pH, temperature, dissolved oxygen (DO), and biochemical oxygen demand (BOD) were determined using standard analytical procedures.

pH and Temperature

The pH and temperature of harvested rainwater samples were measured immediately after sample collection using a calibrated pH meter and temperature probe.

Dissolved Oxygen (DO)

The DO meter was calibrated using 0% and 100% saturation solutions before analysis. The probe was inserted into well-mixed rainwater samples and initial DO readings were recorded. Samples were subsequently incubated for five days at 20 ± 1°C before final DO measurements were taken.

Bacteriological Analysis (Total Coliform)

Total coliform counts were determined using the membrane filtration technique according to the American Public Health Association (APHA, 2017). Samples were filtered through membrane filters and placed on m-Endo agar. The plates were incubated at 35 ± 0.5°C for 24 hours, after which characteristic coliform colonies were counted and expressed as CFU/100 mL.

Health Risk Assessment

Chronic Daily Intake (CDI)

Health risk assessment for heavy metals was conducted using the chronic daily intake (CDI) model according to Ugwu et al. (2022):

$CDI=C\times IR\times EF\times ED\times BW\times AT$

Where:

- C = concentration of metal in water (mg/L)
- IR = ingestion rate
- EF = exposure frequency
- ED = exposure duration
- BW = body weight
- AT = averaging time

Non-Carcinogenic Risk Assessment

Non-carcinogenic risk was evaluated using the Hazard Quotient (HQ):

HQ=CDIRfD

Where:

- CDI = chronic daily intake
- RfD = reference dose

The Hazard Index (HI) was obtained by summing the HQ values for all metals. Values less than 1 indicate negligible health risk,

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while values greater than or equal to 1 indicate potential health risk.

Carcinogenic Risk Assessment

Carcinogenic risk was estimated using the Incremental Lifetime Cancer Risk (ILCR) equation:

ILCR=CDI×CSF

Where:

- CDI = chronic daily intake
- CSF = cancer slope factor

The acceptable cancer risk range was considered to be 1×10^{-6} to 1×10^{-4}, as recommended by the United States Environmental Protection Agency.

Statistical Analysis

A one-way analysis of variance (ANOVA) was used to evaluate significant differences in physicochemical parameters, heavy metal concentrations, and microbiological characteristics across sampling locations and months. Statistical analysis was performed using SPSS, with significance set at $p \le 0.05$. Post-hoc comparisons were conducted using Tukey's HSD test.

Results and Discussion

Physicochemical Properties, Heavy Metals, and Total Coliform Levels of Harvested Rainwater from Corrugated Iron Rooftop (May–September) at Arahan Kunu and Chandal

The results of Physicochemical Properties, Heavy Metals, and Total Coliform Levels of Harvested Rainwater from Corrugated Iron Rooftop (May–September) at Arahan Kunu, Mubi are presented on Table 1.

Temperature

The temperature of harvested rainwater from corrugated iron rooftops at Arahan Kunu ranged from 26.00 ± 0.50 °C to 27.00 ± 0.12 °C, while the control samples ranged from 25.20 ± 0.20 °C to 27.00 ± 0.50 °C. These values were within ambient temperature ranges commonly reported for harvested rainwater in tropical environments and are consistent with guideline recommendations for drinking water quality (WHO, 2017). Temperature is an important water quality parameter because it influences chemical reactions, microbial activity, and dissolved oxygen levels in aquatic systems (APHA, 2017). The slight variations observed across sampling months may be associated with seasonal atmospheric conditions and rainfall intensity.

The temperature of harvested rainwater from corrugated iron rooftops at Chandal ranged from 25.80 ± 0.80 °C to 27.50 ± 0.50 °C, while the control samples ranged from 24.15 ± 0.10 °C to 25.20 ± 0.20 °C. The relatively higher temperatures recorded in the rooftop samples may be attributed to heat absorption by the corrugated iron roofing materials during periods of intense solar radiation. Temperature influences several chemical and biological processes in water, including microbial growth and dissolved oxygen concentration. However, all recorded temperatures were within the acceptable ambient range recommended for potable water, indicating no thermal pollution.

pH

The pH of harvested rainwater at Arahan Kunu ranged from 6.52 ± 0.51 to 7.92 ± 0.12, while the control samples ranged between 7.07 ± 0.07 and 7.40 ± 0.66. All values fell within the WHO recommended guideline range of 6.5–8.5 for potable water (WHO, 2017). Similar pH values have been reported in previous studies on harvested rainwater quality (Boateng et al., 2016; Duncan et al., 2016). The slight variation in pH may be attributed to atmospheric deposition and interaction between rainwater and rooftop surfaces. Near-neutral pH conditions are important because they help maintain water stability and reduce corrosion of roofing materials.

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The pH values of the harvested rainwater at Chandal ranged from 6.80 ± 0.20 to 7.24 ± 0.20, while the control ranged from 7.10 ± 0.20 to 7.40 ± 0.20. These values fall within the permissible limits of 6.5–8.5 recommended by WHO, USEPA, and NAFDAC. The near-neutral pH suggests that the rainwater was neither strongly acidic nor alkaline, indicating minimal atmospheric contamination and acceptable chemical quality for domestic use. The slight variations observed across the months may be associated with differences in rainfall intensity, atmospheric deposition, and rooftop interactions.

Biochemical Oxygen Demand (BOD)

Biochemical oxygen demand (BOD) values for Arahan Kunu ranged from 5.50 ± 0.10 mg/L to 6.90 ± 0.00 mg/L, while the control samples ranged from 5.40 ± 0.20 mg/L to 6.40 ± 0.50 mg/L. The observed values were within permissible limits recommended by USEPA and NAFDAC for drinking water quality. BOD is an indicator of the amount of oxygen required by microorganisms to decompose organic matter in water (APHA, 2017). Variations observed across the sampling months may be associated with the accumulation and wash-off of organic materials such as dust particles, leaves, and animal droppings from rooftop surfaces during rainfall events. Similar findings were reported by Umeobika et al. (2013) in harvested rainwater studies.

Dissolved Oxygen (DO)

The dissolved oxygen (DO) concentrations in harvested rainwater from corrugated iron rooftops at Arahan Kunu ranged from 5.00 ± 0.50 mg/L to 5.45 ± 0.33 mg/L, while the control samples ranged from 5.10 ± 0.10 mg/L to 8.10 ± 0.10 mg/L. These values were generally within the acceptable range recommended for potable water by WHO and USEPA standards. Dissolved oxygen is an important indicator of water quality because it reflects the ability of water to support aerobic biological processes. The slightly lower DO values observed in rooftop-harvested rainwater compared to control samples may be associated with increased microbial activity and the presence of organic matter washed from rooftop surfaces during rainfall events. Similar observations were reported by Duncan et al. (2016), who noted that organic contaminants on roofing materials could influence oxygen dynamics in harvested rainwater systems.

The dissolved oxygen (DO) concentrations at Chandal ranged from 5.50 ± 0.50 mg/L to 6.90 ± 0.10 mg/L in the test samples and 7.00 ± 0.10 mg/L to 8.30 ± 0.30 mg/L in the control samples. These values were within the WHO and USEPA acceptable range of 5–8 mg/L. The lower DO concentrations observed in the rooftop samples compared to the controls may be linked to the higher BOD levels, as microorganisms consume dissolved oxygen during the decomposition of organic materials. Nevertheless, the values still indicate adequate oxygenation and relatively acceptable water quality.

Heavy Metal Concentrations

Zinc concentrations in the Arahan Kunu harvested rainwater samples ranged from 0.30 ± 0.03 mg/L to 0.50 ± 0.10 mg/L, while control samples ranged from 0.03 ± 0.01 mg/L to 0.05 ± 0.01 mg/L. All measured values were well below the WHO permissible limit of 5.0 mg/L. The relatively higher zinc concentrations observed in the rooftop samples compared to the control may be attributed to leaching from the corrugated iron roofing sheets during rainfall. Similar findings were reported by Mendez et al. (2011), who observed elevated zinc concentrations in rainwater harvested from metallic rooftops.

Zinc concentrations in the harvested rainwater at Chandal ranged from 0.30 ± 0.01 mg/L to 0.60 ± 0.06 mg/L, while the control samples ranged from 0.03 ± 0.01 mg/L to 0.14 ± 0.13 mg/L. Although the rooftop samples showed

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higher zinc concentrations than the controls, all values remained far below the permissible limit of 5.0 mg/L established by WHO, USEPA, and NAFDAC. The elevated zinc concentrations in the rooftop samples may be attributed to leaching from the corrugated iron roofing sheets, especially during prolonged rainfall and weathering processes. Despite this, the concentrations recorded are not considered harmful to human health.

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Table 1: Physicochemical Properties, Heavy Metals, and Total Coliform Levels of Harvested Rainwater from Corrugated Iron Rooftop (May–September) at Arahan Kunu, Mubi

Parameters	May Test	May Control	July Test	July Control	Sept Test	Sept Control	WHO (2015)	USEPA (2015)	NAFDAC (2015)
Temperature (°C)	27.00±0.12	27.00 ± 0.50	26.00± 50	25.20± 0.40	27.00±00	25.20± 0.20	Ambient	Ambient	Ambient
Ph	6.52 ± 0.51	7.07 ± 0.07	7.92± .12	7.40 ± 0.50	7.50± .50	7.40 ± 0.66	6.5–8.5	6.5–8.5	6.5–8.5
BOD (mg/L)	5.50 ± 0.10	6.50 ± 0.10	6.90± .00	5.40 ± 0.20	6.00± .10	6.40 ± 0.50	–	5–10	5
DO (mg/L)	5.00 ± 0.50	5.10 ± 0.10	5.450.33	8.10 ± 0.10	5.22± .10	6.10 ± 0.20	5–8	5	5
Pb (mg/L)	ND	ND	ND	ND	ND	ND	0.01	–	0.01
Zn (mg/L)	0.50 ± 0.10	0.05 ± 0.01	0.30± 0.03	0.03 ± 0.01	0.50± .01	0.03 ± 0.01	5.0	5.0	5.0
Cr (mg/L)	0.002± 0.01	ND	0.00± 0.00	ND	0.002± 01	ND	0.05	0.10	0.05
Ni (mg/L)	ND	ND	ND	ND	ND	ND	0.07	0.10	0.15
Cd (mg/L)	ND	ND	ND	ND	ND	ND	0.003	0.005	0.003
Mn (mg/L)	0.11 ± 0.01	0.08 ± 0.01	0.06± .01	0.02 ± 0.01	0.11± .01	0.02 ± 0.01	0.40	0.05	0.05
Total Coliform (CFU/100 mL)	4.50 ± 0.50	4.20 ± 0.15	5.00±0.50	3.50 ± 0.50	5.0± 1.00	2.50 ± 0.50	0	0	0

Mean ± SEM for three determinations (n = 3).
Values with different superscript letters within the same row are significantly different at $p < 0.05$.

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Table 2: Physicochemical Properties, Heavy Metals, and Total Coliform Levels of Harvested Rainwater from Corrugated Iron Rooftop (May–September) at Chandal, Mubi Metropolis

Parameter	May Test	May Control	July Test	July Control	Sept Test	Sept Control	WHO (2015)	USEPA (2015)	NAFDAC (20
Temperature (°C)	27.50±0.50	24.20 ± 0.10	25.80±0.80	25.20 ±0.20	27.50±0.50	24.15 ± 0.10	Ambient	Ambient	Ambient
Ph	7.20 ± 0.30	7.10 ± 0.20	6.80 ± 0.20	7.20 ± 0.00	7.24 ± 0.20	7.40 ± 0.20	6.5–8.5	6.5–8.5	6.5–8.5
BOD (mg/L)	5.60 ± 0.60	5.00 ± 0.00	6.80 ± 0.30	6.40 ± 0.20	6.60 ± 0.50	5.40 ± 0.40	–	5–10	5
DO (mg/L)	6.50 ± 0.40	8.30 ± 0.30	6.90 ± 0.10	7.10 ± 0.20	5.50 ± 0.50	7.00 ± 0.10	5–8	5	5
Pb (mg/L)	ND	ND	ND	ND	ND	ND	0.01	–	0.01
Zn (mg/L)	0.60 ± 0.06	0.14 ± 0.13	0.30 ± 0.01	0.03 ± 0.01	0.60 ± 0.01	0.03 ± 0.01	5.0	5.0	5.0
Cr (mg/L)	0.002 ± 0.01	ND	0.001 ± 0.00	ND	0.002 ± 0.01	ND	0.05	0.10	0.05
Ni (mg/L)	ND	ND	ND	ND	ND	ND	0.07	0.10	0.15
Cd (mg/L)	ND	ND	ND	ND	ND	ND	0.003	0.005	0.003
Mn (mg/L)	0.12 ± 0.01	0.02 ± 0.01	0.03 ± 0.01	0.02 ± 0.01	0.12 ± 0.01	0.04 ± 0.01	0.05	0.05	0.05
Total Coliform (CFU/100 mL)	6.00 ± 1.00	5.00 ± 0.00	5.00 ± 1.00	4.00 ± 0.00	4.00 ± 1.00	3.00 ± 0.00	0	0	0

Mean ± SEM for three determinations (n = 3).
Values with different superscript letters within the same row are significantly different at $p < 0.05$.
ND = Not Detected

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Chromium (Cr)
Chromium concentrations in Arahan Kunu rooftop rainwater ranged from 0.00 ± 0.00 mg/L to 0.002 ± 0.01 mg/L, while chromium was not detected (ND) in any of the control samples. These concentrations were significantly below WHO and USEPA guideline limits, indicating no significant chromium contamination in the harvested rainwater. The low chromium levels suggest minimal atmospheric deposition or roofing material contribution during the study period.

Chromium concentrations at Chandal ranged from 0.001 ± 0.00 mg/L to 0.002 ± 0.01 mg/L in the harvested rainwater, while chromium was not detected in the control samples. These concentrations were considerably below the permissible limits of WHO, USEPA, and NAFDAC. The presence of trace chromium may originate from atmospheric deposition or roofing material corrosion. However, the levels recorded pose no immediate health risk.

Manganese (Mn)
Manganese concentrations ranged from 0.06 ± 0.01 mg/L to 0.11 ± 0.01 mg/L in the Arahan Kunu rooftop samples, while lower concentrations ranging from 0.02 ± 0.01 mg/L to 0.08 ± 0.01 mg/L were observed in the control samples. Although the values were below the WHO guideline limit of 0.40 mg/L, the rooftop values slightly exceeded the USEPA and NAFDAC recommended aesthetic limits of 0.05 mg/L. Manganese occurs naturally in environmental systems and may also originate from suspended dust particles and progressive corrosion of the roofing materials.

Manganese concentrations in the harvested rainwater at Chandal ranged from 0.03 ± 0.01 mg/L to 0.12 ± 0.01 mg/L, while the control samples ranged from 0.02 ± 0.01 mg/L to 0.04 ± 0.01 mg/L. The concentrations recorded in May and September exceeded the permissible limit of 0.05 mg/L recommended by WHO, USEPA, and NAFDAC. The elevated manganese levels may result from corrosion and leaching from the corrugated iron rooftop materials. Excess manganese in drinking water may affect taste, color, and long-term health when consumed continuously at elevated concentrations. Therefore, treatment may be necessary before consumption.

Nickel (Ni), Lead (Pb), and Cadmium (Cd)
Nickel, lead, and cadmium were not detected (ND) in any of the analyzed rainwater or control samples from Arahan Kunu. Their absence indicates that concentrations were below the detection limit of the analytical instrument and suggests minimal contamination from heavy anthropogenic or hazardous roofing-related sources. The non-detection of these toxic metals is structurally important because prolonged exposure to lead and cadmium can result in serious health complications, including neurological and kidney disorders.

At Chandal, Nickel was not detected (ND) in any of the harvested rainwater or control samples throughout the study period. This indicates the absence of nickel contamination and suggests minimal industrial or metallic pollution influence within the Chandal study area.
Lead was also not detected (ND) in either the harvested rainwater or control samples throughout the study period. This finding is significant because lead is highly toxic even at low concentrations and may cause neurological and developmental disorders. The absence of lead suggests that the corrugated iron roofing materials and surrounding environment did not contribute detectable lead contamination to the harvested rainwater at Chandal.

Cadmium was also not detected (ND) in all samples analyzed. Since cadmium is a highly toxic heavy metal associated with kidney damage and other health complications, its absence indicates that the harvested rainwater was free from cadmium pollution and chemically safe with respect to this parameter.

Microbiological Quality
Total coliform counts in harvested rainwater samples at Arahan Kunu ranged from 4.50 ± 0.50 CFU/100 mL to 5.00 ± 0.50 CFU/100 mL, whereas the control samples ranged from 2.50 ± 0.50 CFU/100 mL to 4.20 ± 0.15 CFU/100 mL. The detected coliform levels exceeded the

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WHO permissible limit of 0 CFU/100 mL for drinking water, indicating microbial contamination. The presence of coliform bacteria may result from contamination by bird droppings, dust particles, decaying organic materials, and animal wastes deposited on rooftop surfaces before rainfall. These findings agree with previous studies by Uba and Aghogho (2000) and Lye (2009), which reported that harvested rainwater may contain microbial contaminants if collected without adequate first-flush diversion or treatment systems.

The total coliform counts at Chandal ranged from 4.00 ± 1.00 CFU/100 mL to 6.00 ± 1.00 CFU/100 mL in the harvested rainwater, while the control samples ranged from 3.00 ± 0.00 CFU/100 mL to 5.00 ± 0.00 CFU/100 mL. These values exceeded the WHO, USEPA, and NAFDAC permissible limit of 0 CFU/100 mL for potable water. The presence of coliform bacteria indicates microbial contamination, likely arising from bird droppings, animal waste, dust accumulation, and organic matter deposited on the rooftop surfaces before rainfall. This suggests that the harvested rainwater may not be suitable for direct consumption without proper treatment such as filtration and disinfection.

On a general note, the harvested rainwater from corrugated iron rooftops at Chandal demonstrated acceptable physicochemical characteristics for most parameters measured. However, elevated BOD, manganese, and total coliform levels indicate some degree of organic, metallic, and microbial contamination associated with rooftop runoff. Consequently, although the water may be suitable for some domestic purposes, appropriate treatment is recommended before human consumption to ensure safety and compliance with drinking water standards.

The potential non-carcinogenic health risks associated with the consumption of harvested rainwater from corrugated iron rooftops by adults were evaluated using the Total Hazard Quotient (THQ). The THQ is widely used to estimate the likelihood of adverse health effects resulting from long-term exposure to chemical contaminants through drinking water consumption. A THQ value less than 1 (THQ < 1) indicates that adverse non-carcinogenic health effects are unlikely, whereas a THQ value greater than or equal to 1 (THQ ≥ 1) suggests a possible health risk.

Generally, the physicochemical characteristics of harvested rainwater from corrugated iron rooftops in Arahan Kunu were largely within permissible limits established by WHO, USEPA, and NAFDAC standards. However, the detection of total coliform bacteria above recommended limits indicates that the harvested rainwater is not microbiologically safe for direct consumption without treatment. The elevated microbial load emphasizes the importance of adopting proper rainwater harvesting management practices such as rooftop cleaning, first-flush diversion systems, filtration, and disinfection prior to domestic use.

Additionally, although heavy metal concentrations were generally low and within acceptable limits, the presence of zinc and manganese confirms that roofing materials and ambient dust contribute to trace metal accumulation in harvested rainwater. Continuous monitoring is therefore necessary to ensure long-term safety of harvested rainwater used for drinking and household purposes in Arahan Kunu.

Non-Carcinogenic Health Risk Assessment for Adults

The Target Hazard Quotient (THQ) values for adults consuming harvested rainwater from corrugated iron rooftops across the study locations are presented in Table 3.

The risk assessment results showed that all calculated THQ values for adults were below the recommended safety threshold of 1.0. This indicates that the consumption of harvested rainwater from corrugated iron rooftops is unlikely to pose significant non-carcinogenic health risks to adult consumers within the evaluated study areas.

Among the locations studied, the highest THQ value (0.462) was recorded in Arahan Kunu during May and September within the rooftop test samples. Although this value was the

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highest observed across the study area, it remained comfortably below the critical safety limit of 1.0, suggesting that chronic long-term exposure to trace elements through the consumption of this harvested rainwater is not expected to result in adverse non-carcinogenic health complications in the adult population.

Table 3: Total Hazard Quotient (THQ) of Adults for Corrugated Iron Rooftops

Location	May Test	May Control	July Test	July Control	Sept Test	Sept Control
Arahan Kunu	0.462453	0.168049	0.246258	0.043673	0.462453	0.043642
Chandal	0.321105	0.054119	0.099320	0.043673	0.321105	0.084499

The THQ values recorded in Chandal were moderate compared to those obtained in Arahan Kunu, peaking at (0.321) during the months of May and September. The relatively higher THQ values observed in the test samples of both locations—compared to their respective controls—are directly associated with the leaching of trace metals from the corrugated iron roofing materials, as well as the dry atmospheric deposition of environmental contaminants onto the catchments prior to rainfall events. Seasonal variations in rainfall intensity and the progressive accumulation of rooftop debris across the sampling months further explain the fluctuations observed in the THQ values.

The findings demonstrate that harvested rainwater from corrugated iron rooftops in Arahan Kunu and Chandal poses minimal non-carcinogenic health risks to adults based on the calculated hazard indices. However, continuous monitoring and the adoption of appropriate domestic treatment options (such as first-flush diversion and basic filtration) remain highly recommended to minimize potential long-term cumulative exposure to contaminants and maintain safe potable water quality standards.

Non-Carcinogenic Health Risk Assessment for Children

The Target Hazard Quotient (THQ) values for children consuming harvested rainwater from corrugated iron rooftops across the study locations are presented in Table 4

Table 4: Total Hazard Quotient (THQ) of Children for Corrugated Iron Rooftops

Location	**May Test**	**May Control**	**July Test**	**July Control**	**Sept Test**	**Sept Control**
Arahan Kunu	1.079238	0.392039	0.574605	0.101905	0.679232	0.101880
Chandal	0.749095	0.126324	0.231747	0.101905	0.749095	0.197166

The results showed that most THQ values for children were below the recommended safety threshold of 1.0, indicating minimal non-carcinogenic health risks associated with the consumption of harvested rainwater from corrugated iron rooftops in the majority of the evaluated sampling periods. However, a critical exception was observed in Arahan Kunu during May, where a THQ value of 1.079 was recorded in the rooftop test sample. This value exceeded the acceptable safety risk limit >1.0, suggesting a potential non-carcinogenic health concern for children consuming the harvested rainwater untreated over a prolonged period.

The elevated THQ value recorded in Arahan Kunu during May can be attributed to increased concentrations of trace metals in the harvested rainwater during the onset of the rainy season. This spike is highly indicative of the first-flush phenomenon, where atmospheric pollutants, suspended dust particles, and metallic contaminants that accumulated heavily on the rooftop surfaces during the preceding dry season are washed into the collection system during the first intense rainfall events.

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In Chandal, child THQ values for trace contaminants ranged from 0.126 to 0.749, with all measurements falling below the 1.0 critical risk threshold. While not posing an immediate health hazard, the highest indices occurred in May and September (0.749), indicating moderate exposure levels compared to the lower July readings (0.232).

When compared systematically, the THQ values obtained for children were visibly higher than those recorded for adults across all sampling points in both Arahan Kunu and Chandal. This observation reflects the well-documented developmental susceptibility of children to environmental pollutants, driven by their smaller body surface area, lower body weight, and higher fluid intake rates relative to their body mass.

The findings indicate that while harvested rainwater from corrugated iron rooftops poses a low non-carcinogenic health risk to children during most months, the early rainy season (May) in Arahan Kunu presents a clear exposure risk. Consequently, implementing first-flush diversion systems, domestic filtration, and routine water quality monitoring is crucial before this water is supplied to vulnerable populations, particularly children.

Carcinogenic Risk Assessment

The carcinogenic risks associated with exposure to heavy metals through the consumption of harvested rainwater from corrugated iron rooftops were evaluated using the Incremental Lifetime Cancer Risk (ILCR) model. The ILCR estimates the statistical probability of an individual developing cancer over a lifetime as a direct result of exposure to specific carcinogenic contaminants. According to international regulatory guidelines, an ILCR value within the range of 1.0 x 10^-6 to 1.0 x 10^-4 (1 in a million to 1 in 10,000) is considered acceptable or tolerable, while values exceeding 1.0 x 10^-4 indicate significant potential carcinogenic health concerns that demand regulatory intervention.

Cancer Risk for Adults

The Incremental Lifetime Cancer Risk (ILCR) values for adults consuming harvested rainwater from corrugated iron rooftops are presented in Table 5.

Table 5: Incremental Lifetime Cancer Risk (ILCR) for Adults – Corrugated Iron Rooftops

Location	May Test	July Test	Sept Test
Arahan Kunu	5.7×10^{-5}	2.86×10^{-5}	5.7×10^{-5}
Chandal	5.7×10^{-6}	2.86×10^{-6}	5.7×10^{-6}

The results also revealed that the highest ILCR value for adults (5.70 x 10^-5) was recorded in Arahan Kunu during May and September. Although this was the highest value observed across the evaluated areas, it falls entirely within the acceptable carcinogenic risk range of 1.0 x 10^-6 to 1.0 x 10^-4 recommended by international health and environmental regulatory agencies. This suggests that the carcinogenic risk associated with the long-term consumption of harvested rainwater from corrugated iron rooftops is relatively low for adults.

Lower ILCR values were observed in Chandal, ranging from 2.86 x 10^-6 to 5.70 x 10^-6, indicating very low carcinogenic risk levels. The relatively higher ILCR values observed in Arahan Kunu may be linked to the presence of trace metal contaminants introduced through mechanical rooftop corrosion, localized atmospheric deposition, and accumulated environmental pollutants during the dry season prior to rainfall events.

Cancer Risk for Children

The carcinogenic risk associated with the consumption of harvested rainwater by children was also evaluated using the ILCR model. Children are generally more susceptible to carcinogenic contaminants because of their lower body weight, developing organs, and higher exposure rates relative to body mass. The breakdown of these risks is presented in Table 6.

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Table 6: Incremental Lifetime Cancer Risk (ILCR) for Children – Corrugated Iron Rooftops

Table 6: Incremental Lifetime Cancer Risk (ILCR) for Children – Corrugated Iron Rooftops

Location	**May Test**	**July Test**	**Sept Test**
Arahan Kunu	1.23×10^{-4}	6.12×10^{-5}	1.23×10^{-4}
Chandal	1.23×10^{-5}	6.12×10^{-6}	1.23×10^{-5}

The results revealed that the highest ILCR value for children (1.23 x 10^-4) was recorded in Arahan Kunu during May and September. This value slightly exceeded the recommended acceptable safety threshold of 1.0 x 10^-4, suggesting a potential carcinogenic health risk for children consuming untreated harvested rainwater over prolonged periods.

The elevated ILCR values observed in Arahan Kunu may be associated with increased concentrations of carcinogenic trace metals during the early rainfall periods, possibly due to the washing of accumulated contaminants from rooftop surfaces after prolonged dry seasons. Seasonal atmospheric deposition and roofing material corrosion may also have contributed to the observed carcinogenic risk levels.

In Chandal, the ILCR values ranged from 6.12 x 10^-6 to 1.23 x 10^-5, which fall well within the acceptable carcinogenic risk range and indicate relatively low cancer risk for children within this location.

On a general note, the ILCR values obtained for children were higher than those recorded for adults across the study locations, confirming that children are more vulnerable to carcinogenic contaminants present in harvested rainwater catchments. Overall, most ILCR values obtained in this study were within the acceptable carcinogenic risk range recommended by international guidelines, indicating generally low cancer risks associated with the consumption of harvested rainwater from corrugated iron rooftops. However, the slightly elevated ILCR values observed for children in Arahan Kunu suggest that untreated harvested rainwater may pose potential long-term carcinogenic health concerns for vulnerable populations. Therefore, proper treatment and continuous monitoring of harvested rainwater are recommended before consumption.

Table 7: Incremental Lifetime Cancer Risk (ILCR) for Children – Corrugated Iron Rooftops

Location	May Test	July Test	Sept Test
Arahan Kunu	1.23×10^{-4}	6.12×10^{-5}	1.23×10^{-4}
Chandal	1.23×10^{-5}	6.12×10^{-6}	1.23×10^{-5}

Physicochemical The results revealed that the highest ILCR value for children (1.23×10^{-4}) was recorded in Arahan Kunu during May and September. This value slightly exceeded the recommended acceptable threshold of 1.0×10^{-4}, suggesting a potential carcinogenic health risk for children consuming untreated harvested rainwater over prolonged periods.

The elevated ILCR values observed in Arahan Kunu may be associated with increased concentrations of carcinogenic trace metals during the early rainfall periods, possibly due to the washing of accumulated contaminants from rooftop surfaces after prolonged dry seasons. Seasonal atmospheric deposition and roofing material corrosion may also have contributed to the observed carcinogenic risk levels.

In Chandal, the ILCR values ranged from 6.12×10^{-6} to 1.23×10^{-5}, which fall within the acceptable carcinogenic risk range and

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indicate relatively low cancer risk for children..

Generally, the ILCR values obtained for children were higher than those recorded for adults across the study locations, indicating that children are more vulnerable to carcinogenic contaminants present in harvested rainwater. Overall, most ILCR values obtained in this study were within the acceptable carcinogenic risk range recommended by international guidelines, indicating generally low cancer risks associated with the consumption of harvested rainwater from corrugated iron rooftops. However, the slightly elevated ILCR values observed for children in Arahan Kunu suggest that untreated harvested rainwater may pose potential long-term carcinogenic health concerns for vulnerable populations. Therefore, proper treatment and continuous monitoring of harvested rainwater are recommended before consumption.

This study assessed the physicochemical properties, heavy metal concentrations, microbial quality, and potential health risks associated with harvested rainwater collected from corrugated iron rooftops in Arahan Kunu and Chandal within Mubi, Adamawa State, Nigeria. The findings revealed variations in water quality across the sampling locations and seasons, reflecting the direct influence of rooftop materials, atmospheric deposition, environmental conditions, and seasonal rainfall patterns on harvested rainwater quality.

Most of the physicochemical parameters analyzed, including temperature, pH, dissolved oxygen, zinc, chromium, nickel, cadmium, and manganese, were within the permissible limits recommended by the World Health Organization (WHO), United States Environmental Protection Agency (USEPA), and National Agency for Food and Drug Administration and Control (NAFDAC). Lead, nickel, and cadmium were not detected in the samples, indicating minimal contamination from these toxic heavy metals. However, slightly elevated Biochemical Oxygen Demand (BOD) values recorded in some samples suggest the presence of biodegradable organic matter in the harvested rainwater, likely resulting from rooftop contaminants such as dust particles, bird droppings, leaves, and other organic debris.

The microbiological assessment showed that total coliform counts in all sampled locations exceeded the recommended limit of 0 CFU/100 mL for potable water. This indicates widespread microbial contamination of the harvested rainwater and confirms that the water is not suitable for direct human consumption without treatment. The contamination originated from environmental pollutants, animal wastes, and organic materials deposited on rooftop surfaces prior to rainfall events.

The non-carcinogenic health risk assessment revealed that most Total Hazard Quotient (THQ) values for both adults and children were below the acceptable safety threshold of 1.0, indicating minimal non-carcinogenic health risks associated with the consumption of harvested rainwater from corrugated iron rooftops. However, a child THQ value above 1.0 was recorded in Arahan Kunu during May, suggesting a definitive non-carcinogenic health concern for vulnerable populations if untreated rainwater is consumed continuously over long periods.

Similarly, the carcinogenic risk assessment showed that most Incremental Lifetime Cancer Risk (ILCR) values for adults and children were within the acceptable risk range of 1.0 x 10^-6 to 1.0 x 10^-4, indicating a generally low carcinogenic risk. Nevertheless, the slightly elevated ILCR values observed for children in Arahan Kunu during May and September exceed the 1.0 x 10^-4 safety limit, highlighting potential long-term carcinogenic

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health concerns associated with prolonged consumption of untreated harvested rainwater.

Overall, the study demonstrated that harvested rainwater from corrugated iron rooftops in the study area possesses relatively acceptable physicochemical quality and low heavy metal contamination. However, microbial contamination and the potential health risks identified in Arahan Kunu indicate that harvested rainwater should not be consumed directly without appropriate treatment. Therefore, proper rainwater treatment methods such as filtration, boiling, chlorination, and regular maintenance of rooftop catchment systems are strongly recommended before domestic use, particularly for drinking purposes. Continuous monitoring and public awareness programs are also necessary to ensure the safe utilization of harvested rainwater and to minimize potential public health risks in Mubi.

Conclusion

This study carried out a comprehensive assessment of the physicochemical properties, heavy metal concentrations, microbiological quality, and human toxicological health risks of rainwater harvested from corrugated iron rooftops in Arahan Kunu and Chandal within Mubi, Adamawa State, Nigeria. The research established that environmental parameters and water quality safety vary significantly across sampling coordinates and seasonal timelines. These fluctuations directly reflect the compounded impacts of rooftop material degradation, ambient dry-season atmospheric deposition, localized environmental activities, and shifting precipitation intensity.

Analyses of the primary physicochemical parameters—including temperature, pH, dissolved oxygen (DO), zinc (Zn), chromium (Cr), nickel (Ni), cadmium (Cd), and manganese (Mn)—showed that they generally align with the maximum permissible thresholds established by the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA), and the National Agency for Food and Drug Administration and Control (NAFDAC). Highly toxic heavy metals, specifically lead (Pb), nickel (Ni), and cadmium (Cd), were not detected across the sampling stations, confirming that the corrugated iron catchments within these specific communities do not present immediate systemic hazards for these elements. However, the presence of trace zinc and manganese, coupled with slightly elevated Biochemical Oxygen Demand (BOD) values, points to minor metallic leaching from the weathered corrugated sheets and organic contamination driven by rooftop debris like dust, dry leaves, and avian droppings.

In contrast to the acceptable chemical profiles, the microbiological assessment revealed a critical public health concern. Total coliform counts consistently exceeded the mandatory regulatory threshold of 0 CFU/100 mL across both Arahan Kunu and Chandal during all sampling months from May to September. This widespread microbial loading demonstrates that raw harvested rainwater from metallic roofs in these areas is heavily contaminated by environmental pollutants and animal wastes, making it entirely unsafe for direct human consumption without prior treatment.

The human health risk modeling provided vital baseline insight into population exposure pathways. The non-carcinogenic risk index showed that Total Hazard Quotient (THQ) values for adults and children remained safely below the critical 1.0 threshold during most months. However, a significant exception was recorded for children in Arahan Kunu during May, where the THQ reached 1.079. This statistical exceedance indicates a potential non-carcinogenic health hazard for the youth population, driven by the first-flush phenomenon at the onset of the rainy season.

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Similarly, the carcinogenic risk assessment showed that most Incremental Lifetime Cancer Risk (ILCR) values fell within the internationally accepted range of 1.0 x 10^-6 to 1.0 x 10^-4. Nevertheless, children in Arahan Kunu during May and September exhibited an elevated ILCR of 1.23 x 10^-4, which edges past the safe regulatory limit and signals potential long-term cancer risks if untreated water is ingested over an extended lifetime.

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