



## **Heavy Metal Contamination in Roof-Harvested Rainwater from Different Roofing Materials in Calabar Metropolis, Nigeria**

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### **Abstract**

The increasing reliance on roof-harvested rainwater as an alternative water source in many developing regions raises concerns regarding its safety, particularly due to contamination from roofing materials and environmental deposition. This study assessed the concentrations of selected heavy metals (cadmium, lead, arsenic, nickel, and copper) in rainwater collected from different roofing materials (Nigerian zinc, Cameroon zinc, long-span aluminium, and corrugated roofing sheets) of varying ages (0–5, 6–10, 11–15, 16–20, and  $\geq 20$  years) within Calabar Metropolis, Nigeria. Rainwater samples were collected during rainfall events and analyzed using standard analytical techniques, including hydride generation spectrophotometry, electrothermal atomic absorption spectrometry, and dithizone extraction methods. Data were statistically analyzed using one-way ANOVA. Results revealed a significant increase in cadmium, lead, arsenic, and copper concentrations with increasing roofing age ( $P < 0.001$ ) across most roofing types. Cadmium levels in Nigerian zinc roofs increased from  $0.10 \pm 0.01$  mg/L to  $1.30 \pm 0.61$  mg/L, while lead concentrations in corrugated roofs increased from  $0.22 \pm 0.01$  mg/L to  $0.60 \pm 0.01$  mg/L. Arsenic exhibited a marked increase across all roofing types, with Cameroon zinc roofs recording the highest values (up to  $22.80 \pm 0.01$  mg/L). Copper concentrations also increased significantly with roof age, reaching  $2.10 \pm 0.01$  mg/L in Nigerian zinc roofs. Nickel was not detected in any roofing samples, indicating minimal contribution from roofing materials. Control and bottled water samples generally showed negligible or stable metal concentrations. The findings demonstrate that roofing material type and age significantly influence heavy metal contamination in harvested rainwater, with progressive leaching observed in older roofing systems. This poses potential public health risks when such water is consumed without treatment. Regular monitoring of roof-harvested rainwater, replacement of aged roofing materials, and appropriate treatment interventions are therefore recommended to safeguard water quality.

**Keywords:** Rainwater harvesting, heavy metals, roofing materials, cadmium, lead, arsenic, water quality.

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<https://doi.org/10.61594/tnpr.v7i4.2026.181>

Page No.: 348-354

Volume: Volume 7 Issue 4, 2026

Trends in Natural Products Research

Copy Right: NAPREG

Received 23/6/26, Revised 9/7/26, Accepted 20/7/26, Published Online 30/9/2026

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## Introduction

Water is an essential natural resource that sustains life and supports domestic, agricultural, and industrial activities. However, the availability of safe drinking water is increasingly threatened by pollution, rapid urbanization, and environmental degradation, particularly in developing regions where conventional water supply systems remain inadequate (Huang, *et al.*, 2021; Khoso, *et al.*, 2014). As a result, many households rely on alternative sources such as rainwater harvesting from rooftops to meet daily water demands (Frimpong, 2016).

Although rainwater is naturally considered relatively clean, its quality can be significantly compromised during collection and storage, especially when roof catchment systems are used. Roofing materials are now recognized as a major source of chemical contamination in harvested rainwater, particularly through leaching processes influenced by rainfall acidity and atmospheric deposition (Müller *et al.*, 2019). Studies have shown that metallic roofing surfaces can release toxic heavy metals into runoff water, including lead (Pb), cadmium (Cd), copper (Cu), arsenic (As), and nickel (Ni), thereby altering its safety for human consumption (Mendez *et al.*, 2011; Zdeb *et al.*, 2020).

Dry atmospheric deposition further contributes to this contamination process, as airborne particulates from industrial emissions, vehicular activities, and anthropogenic sources settle on roof surfaces and are subsequently washed into rainwater systems during rainfall events (Despins *et al.*, 2009; Lee *et al.*, 2010). In addition, the chemical composition and age of roofing materials influence the extent of metal leaching, with older and corroded roofs typically releasing higher concentrations of heavy metals into harvested rainwater (Charters *et al.*, 2021; De Buyck *et al.*, 2021).

Several studies have reported elevated concentrations of toxic metals in roof-harvested rainwater. For instance, Akoto *et al.* (2011) observed significant levels of Pb and Cd in runoff from roofing sheets compared to control samples, while Van Metre and Mahler (2003) also reported that galvanized metal roofs contribute substantially to Cd and Pb contamination. These findings are particularly concerning because heavy metals are non-biodegradable, persistent, and capable of bioaccumulating in human tissues, leading to long-term health risks (Jaishankar *et al.*, 2014; Tchounwou *et al.*, 2012).

From a toxicological perspective, cadmium exposure has been associated with renal dysfunction, hepatic damage, osteomalacia, and oxidative stress-mediated cellular damage (Tinkov *et al.*, 2018). Lead exposure

is particularly dangerous in children, where it impairs neurological development and cognitive function even at low concentrations (WHO, 2019). Furthermore, heavy metals such as Cd and Pb have been classified as Group 1 carcinogens due to their ability to induce DNA damage, oxidative stress, and disruption of cellular processes (Pearce *et al.*, 2015). Chronic exposure has also been linked to endocrine disruption, reproductive toxicity, and neurodegenerative diseases (Bodor *et al.*, 2021).

Despite increasing reliance on rainwater harvesting systems, especially in developing countries like Nigeria, limited attention has been given to how roofing materials and their aging conditions influence heavy metal contamination in harvested rainwater. This gap in knowledge necessitates a systematic assessment of heavy metal levels in roof-harvested rainwater to evaluate potential public health risks.

This study was designed to assess the levels of selected heavy metals (Cd, Pb, Cu, As, and Ni) in rainwater collected from different types and ages of roofing sheets within Calabar metropolis, with the aim of evaluating the potential contamination risks associated with roof-harvested rainwater intended for domestic use.

## Materials and Methods

### Study Area and Sample Collection

Rainwater samples were collected from four roofing types; Nigerian zinc, Cameroonian zinc, long-span aluminium, and corrugated roofing sheets installed on residential buildings of varying ages (0–5, 6–10, 11 – 15, and 16 –20, > 20 years) within Calabar Metropolis, Nigeria. Sampling was carried out during rainfall events in July, August, and September 2024.

Rainwater was collected directly into pre-cleaned polyethylene containers rinsed with distilled water. Control samples included direct rainfall (roof-free collection) and packaged bottled water obtained from a certified treatment facility.

### Sample Handling

All samples were transported immediately to the laboratory in ice-cooled containers and analyzed for physicochemical properties following standard analytical procedures.

### Determination of Heavy Metals

Heavy metal concentrations in harvested rainwater samples were determined using standard analytical procedures. Arsenic (As) was determined using the

hydride generation method, in which arsenic species were reduced to arsine gas ( $\text{AsH}_3$ ) using sodium borohydride under acidic conditions and quantified spectrophotometrically at 520 nm (Aggett & Aspell, 1976; APHA, 2017). Cadmium (Cd) and nickel (Ni) were determined by electrothermal atomic absorption spectrometry (ETAAS) using a graphite furnace atomizer (Welz & Sperling, 1999; APHA, 2017). Lead (Pb) was analyzed using the dithizone extraction method, where lead ions were complexed with dithizone and measured spectrophotometrically at 510 nm (Vogel, 1989; AOAC International, 2019). Copper (Cu) was determined by a spectrophotometric method based on the formation of a colored copper complex following acid treatment and calibration with standard copper solutions (Marczenko & Balcerzak, 2000; APHA, 2017). Calibration curves prepared from analytical standards were used for quantification of all metals. Results were expressed as mg/L (American Public Health Association 2017; AOAC 2019).

#### *Statistical Analysis*

All analyses were conducted in triplicate and results expressed as mean  $\pm$  standard deviation. Data were subjected to one-way analysis of variance (ANOVA) to determine significant differences among roofing sheet types and age categories. Mean separation was performed using Duncan's Multiple Range Test, and differences were considered statistically significant at  $P < 0.05$ .

### **Results**

#### *Cadmium Concentrations in rainwater*

Cadmium levels increased significantly ( $P < 0.001$ ) with increasing roofing age across all roofing types. For Nigerian Zinc (NZ), cadmium concentration increased from  $0.10 \pm 0.01$  mg/L at 0–5 years to  $1.30 \pm 0.61$  mg/L at  $\geq 20$  years. Similarly, Cameroon Zinc (CZ) exhibited a gradual increase from  $0.01 \pm 0.01$  mg/L to  $0.41 \pm 0.01$  mg/L over the same period. Long Span (LS) roofing sheets recorded cadmium concentrations ranging from  $0.00 \pm 0.00$  mg/L at 0–5 years to  $0.80 \pm 0.01$  mg/L at  $\geq 20$  years, while Corrugated Zinc (COR) had  $0.06 \pm 0.01$  mg/L to  $0.60 \pm 0.01$  mg/L (Table 1). Cadmium was not detected in either the normal control (NC) or bottled table water standard (BTW STD) samples throughout the study period.

#### *Arsenic concentrations in rainwater*

Arsenic levels increased significantly ( $P < 0.001$ ) with roofing age in all roofing types. Nigerian Zinc (NZ)

showed an increase from  $5.29 \pm 0.01$  mg/L at 0–5 years to  $20.34 \pm 0.01$  mg/L at  $\geq 20$  years. Cameroon Zinc (CZ) consistently recorded the highest arsenic concentrations, increasing from  $14.30 \pm 0.01$  mg/L to  $22.80 \pm 0.01$  mg/L. Long Span (LS) roofing sheets had arsenic concentrations  $6.12 \pm 0.01$  mg/L to  $12.93 \pm 0.01$  mg/L, while in Corrugated Zinc (COR) arsenic concentrations increased from  $6.20 \pm 0.01$  mg/L to  $9.73 \pm 0.01$  mg/L (Table 2). The arsenic concentration of the normal control remained constant at  $12.92 \pm 0.01$  mg/L, whereas the bottled table water standard remained constant at  $32.13 \pm 0.06$  mg/L throughout the study period.

#### *Lead concentrations in rainwater*

Lead concentrations significantly differed ( $P < 0.001$ ) among roofing types and age categories (Table 3). Nigerian Zinc (NZ) exhibited a gradual increase in lead concentration from  $0.02 \pm 0.01$  mg/L at 0–5 years to  $0.07 \pm 1.00$  mg/L at  $\geq 20$  years. Lead concentrations in Cameroon Zinc (CZ) increased from  $0.00 \pm 0.00$  mg/L to  $0.04 \pm 0.01$  mg/L during the study period. Corrugated Zinc (COR) recorded the highest lead concentrations, increasing from  $0.22 \pm 0.01$  mg/L at 0–5 years to  $0.60 \pm 0.01$  mg/L at  $\geq 20$  years. Lead was not detected in Long Span (LS) roofing sheet samples across all age categories, and neither in the normal control nor bottled table water standard samples.

#### *Nickel concentrations in rainwater*

Nickel was not detected in any of the roofing sheet samples throughout the study period, with all values remaining at  $0.00 \pm 0.00$  mg/L. Similarly, nickel was not detected in the bottled table water standard. However, the normal control recorded a constant concentration of  $0.01 \pm 0.01$  mg/L across all sampling periods (Table 4). Statistical analysis indicated significant differences ( $P < 0.001$ ) among the samples.

#### *Copper concentrations in rainwater*

Copper levels increased significantly ( $P < 0.001$ ) with roofing age across all roofing types. Nigerian Zinc (NZ) recorded the highest copper concentrations, increasing from  $0.16 \pm 0.01$  mg/L at 0–5 years to  $2.10 \pm 0.01$  mg/L at  $\geq 20$  years. Copper concentrations in Cameroon Zinc (CZ) showed a gradual increase from  $0.00 \pm 0.00$  mg/L to  $0.14 \pm 0.01$  mg/L, while Copper concentrations in Long Span (LS) increased from  $0.00 \pm 0.00$  mg/L to  $0.14 \pm 0.01$  mg/L over the study period. Corrugated Zinc (COR) also exhibited an increase Copper concentration in from  $0.30 \pm 0.01$  mg/L at 0–5 years to  $0.70 \pm 0.01$  mg/L at  $\geq 20$  years. The normal control maintained a constant copper concentration of

0.53 ± 0.01 mg/L throughout the study period, whereas the bottled table water standard remained constant at 0.12 ± 0.01 mg/L (Table 5)

**Table 1:** Cadmium (mg/L) level of rain water collected from different roofing sheets

| Years     | NZ                        | CZ                        | LS                       | COR                      | NC          | BTW         |
|-----------|---------------------------|---------------------------|--------------------------|--------------------------|-------------|-------------|
| 0 – 5     | 0.10 ± 0.01 <sup>b</sup>  | 0.01 ± 0.01 <sup>ab</sup> | 0.00 ± 0.00 <sup>a</sup> | 0.06 ± 0.01 <sup>b</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| 6 – 10    | 0.30 ± 1.00 <sup>ab</sup> | 0.02 ± 0.01 <sup>ab</sup> | 0.25 ± 0.01 <sup>b</sup> | 0.23 ± 0.01 <sup>c</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| 11 – 15   | 0.30 ± 0.01 <sup>ab</sup> | 0.03 ± 0.01 <sup>b</sup>  | 0.33 ± 0.01 <sup>c</sup> | 0.40 ± 0.01 <sup>d</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| 16 – 20   | 0.80 ± 0.01 <sup>bc</sup> | 0.40 ± 0.01 <sup>c</sup>  | 0.62 ± 0.01 <sup>d</sup> | 0.53 ± 1.00 <sup>e</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| ≥ 20      | 1.30 ± 0.61 <sup>c</sup>  | 0.41 ± 0.01 <sup>c</sup>  | 0.80 ± 0.01 <sup>e</sup> | 0.60 ± 0.01 <sup>f</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| Statistic | P= <0.001                 | P= <0.001                 | P= <0.001                | P= <0.001                | P= <0.001   | P= <0.001   |

Data are presented as mean ± SD; n = 3. and values with different superscripts indicate significant difference (P < 0.001); Key: NZ = Nigerian Zinc, CZ = Cameroon zinc, COR = Corrugated zinc, LS = Long span, BTW= Bottled table water; NC = Normal Control

**Table 2:** Arsenic (mg/L) level of rain water collected from different roofing sheets

| Years     | NZ                        | CZ                        | LS                        | COR                      | NC                        | BTW          |
|-----------|---------------------------|---------------------------|---------------------------|--------------------------|---------------------------|--------------|
| 0 – 5     | 5.29 ± 0.01 <sup>a</sup>  | 14.30 ± 0.01 <sup>a</sup> | 6.12 ± 0.01 <sup>a</sup>  | 6.20 ± 0.01 <sup>a</sup> | 12.92 ± 0.01 <sup>e</sup> | 32.13 ± 0.06 |
| 6 – 10    | 5.65 ± 0.01 <sup>b</sup>  | 16.55 ± 0.01 <sup>b</sup> | 7.03 ± 0.01 <sup>b</sup>  | 6.61 ± 0.01 <sup>b</sup> | 12.92 ± 0.01 <sup>e</sup> | 32.13 ± 0.06 |
| 11 – 15   | 7.51 ± 0.01 <sup>c</sup>  | 18.65 ± 0.0 <sup>c</sup>  | 7.88 ± 0.01 <sup>c</sup>  | 7.30 ± 0.01 <sup>c</sup> | 12.92 ± 0.01 <sup>e</sup> | 32.13 ± 0.06 |
| 16 – 20   | 15.65 ± 0.01 <sup>d</sup> | 20.20 ± 0.01 <sup>d</sup> | 9.20 ± 0.01 <sup>d</sup>  | 8.50 ± 0.01 <sup>d</sup> | 12.92 ± 0.01 <sup>e</sup> | 32.13 ± 0.06 |
| ≥ 20      | 20.34 ± 0.01 <sup>e</sup> | 22.80 ± 0.01 <sup>e</sup> | 12.93 ± 0.01 <sup>e</sup> | 9.73 ± 0.01 <sup>e</sup> | 12.92 ± 0.01 <sup>e</sup> | 32.13 ± 0.06 |
| Statistic | P= <0.001                 | P= <0.001                 | P= <0.001                 | P= <0.001                | P= <0.001                 | P= <0.001    |

Data are presented as mean ± SD; n = 3. and values with different superscripts indicate significant difference (P < 0.001); Key: NZ = Nigerian Zinc, CZ = Cameroon zinc, COR = Corrugated zinc, LS = Long span, BTW= Bottled table water; NC = Normal Control

**Table 3:** Lead (mg/L) level of rain water collected from different roofing sheets

| Years     | NZ                        | CZ                         | LS          | COR                      | NC          | BTW         |
|-----------|---------------------------|----------------------------|-------------|--------------------------|-------------|-------------|
| 0 – 5     | 0.02 ± 0.01 <sup>bc</sup> | 0.00 ± 0.00 <sup>a</sup>   | 0.00 ± 0.00 | 0.22 ± 0.01 <sup>b</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| 6 – 10    | 0.04 ± 1.00 <sup>bc</sup> | 0.01 ± 0.01 <sup>ab</sup>  | 0.00 ± 0.00 | 0.36 ± 0.01 <sup>c</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| 11 – 15   | 0.05 ± 0.01 <sup>c</sup>  | 0.02 ± 0.01 <sup>abc</sup> | 0.00 ± 0.00 | 0.40 ± 0.01 <sup>d</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| 16 – 20   | 0.06 ± 0.0 <sup>cd</sup>  | 0.03 ± 0.01 <sup>bc</sup>  | 0.00 ± 0.00 | 0.51 ± 0.0 <sup>e</sup>  | 0.00 ± 0.00 | 0.00 ± 0.00 |
| ≥ 20      | 0.07 ± 1.00 <sup>a</sup>  | 0.04 ± 0.01 <sup>c</sup>   | 0.00 ± 0.00 | 0.60 ± 0.01 <sup>f</sup> | 0.00 ± 0.00 | 0.00 ± 0.00 |
| Statistic | P= <0.001                 | P= <0.001                  | P= <0.001   | P= <0.001                | P= <0.001   | P= <0.001   |

Data are presented as mean ± SD; n = 3. and values with different superscripts indicate significant difference (P < 0.001); Key: NZ = Nigerian Zinc, CZ = Cameroon zinc, COR = Corrugated zinc, LS = Long span, BTW= Bottled table water; NC = Normal Control

**Table 4:** Nickel (mg/L) level of rain water collected from different roofing sheets

| Years     | NZ         | CZ         | LS         | COR        | NC          | BTW                      |
|-----------|------------|------------|------------|------------|-------------|--------------------------|
| 0         | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.01 <sup>a</sup> |
| 5         | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.01 <sup>a</sup> |
| 10        | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.01 <sup>a</sup> |
| 15        | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.01 <sup>a</sup> |
| 20        | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | .00 ± 0.00 | 0.00 ± 0.00 | 0.01 ± 0.01 <sup>a</sup> |
| Statistic | P= <0.001  | P= <0.001  | P= <0.001  | P= <0.001  | P= <0.001   | P= <0.001                |

Data are presented as mean ± SD; n = 3. and values with different superscripts indicate significant difference (P < 0.001); Key: NZ = Nigerian Zinc, CZ = Cameroon zinc, COR = Corrugated zinc, LS = Long span, BTW= Bottled table water; NC = Normal Control

**Table 5:** Copper (Mg/L) level of rain water collected from different roofing sheets

| Years     | NZ                        | CZ                        | LS                        | COR                       | NC                       | BTW         |
|-----------|---------------------------|---------------------------|---------------------------|---------------------------|--------------------------|-------------|
| 0 – 5     | 0.16 ± 0.01 <sup>b</sup>  | 0.00 ± 0.00 <sup>a</sup>  | 0.00 ± 0.00 <sup>a</sup>  | 0.30 ± 0.01 <sup>b</sup>  | 0.53 ± 0.01 <sup>b</sup> | 0.12 ± 0.01 |
| 6 – 10    | 0.18 ± 0.01 <sup>b</sup>  | 0.06 ± 0.01 <sup>b</sup>  | 0.01 ± 0.01 <sup>b</sup>  | 0.33 ± 0.01 <sup>c</sup>  | 0.53 ± 0.01 <sup>b</sup> | 0.12 ± 0.01 |
| 11 – 15   | 1.75 ± 0.010 <sup>c</sup> | 0.11 ± 0.01 <sup>c</sup>  | 0.12 ± 0.01 <sup>bc</sup> | 0.53 ± 0.01 <sup>bc</sup> | 0.53 ± 0.01 <sup>b</sup> | 0.12 ± 0.01 |
| 16– 20    | 1.80 ± 0.01 <sup>d</sup>  | 0.13 ± 0.01 <sup>cd</sup> | 0.12 ± 0.01 <sup>bc</sup> | 0.63 ± 1.00 <sup>cd</sup> | 0.53 ± 0.01 <sup>b</sup> | 0.12 ± 0.01 |
| ≥ 20      | 2.10 ± 0.01 <sup>c</sup>  | 0.14 ± 0.01 <sup>d</sup>  | 0.14 ± 0.01 <sup>c</sup>  | 0.70 ± 0.01 <sup>a</sup>  | 0.53 ± 0.01 <sup>b</sup> | 0.12 ± 0.01 |
| Statistic | P= <0.001                 | P= <0.001                 | P= <0.001                 | P= <0.001                 | P= <0.001                | P= <0.001   |

Data are presented as mean ± SD; n = 3. and values with different superscripts indicate significant difference (P < 0.001); Key: NZ = Nigerian Zinc, CZ = Cameroon zinc, COR = Corrugated zinc, LS = Long span, BTW= Bottled table water; NC = Normal Control

## Discussion

The present study demonstrated that roofing material type and age significantly influenced the accumulation of heavy metals in harvested rainwater. Cadmium, lead, copper, and arsenic concentrations generally increased with increasing roof age, indicating progressive weathering and leaching of roofing materials over time. These increases were particularly evident in Nigerian zinc (NZ) and corrugated zinc (COR) roofing sheets, suggesting that prolonged environmental exposure may enhance the release of metal constituents into harvested rainwater. The progressive increase in cadmium concentration with increasing roof age suggests continuous leaching from roofing materials and deposition of airborne contaminants. Similar observations were reported by Akoto *et al.*, (2011) who found elevated cadmium concentrations in roof runoff compared with control rainwater samples. The concentrations recorded in older roofing sheets exceeded the bottled table water standard, indicating potential health concerns for untreated domestic use. The elevated lead levels observed in older corrugated roofing sheets may be associated with long-term corrosion and atmospheric deposition. Similar findings have been reported by Mendez *et al.*, (2011) and Zdeb *et al.*, (2020) who

observed greater contaminant loads in roof runoff than in direct rainfall samples.

Arsenic concentrations exhibited a consistent increase with roofing age in all roofing categories. Cameroon zinc roofs recorded the highest arsenic levels, followed by Nigerian zinc roofs. Although all these values remained below the bottled table water standard used in this study, the upward trend suggests progressive accumulation associated with roof ageing and environmental exposure. The higher arsenic concentrations recorded in Cameroon zinc roofs may reflect differences in roofing composition, manufacturing processes, or susceptibility to weathering. Copper concentrations likewise increased significantly with increasing roof age. Nigerian zinc roofs recorded the highest copper concentration. The substantial increase observed in Nigerian zinc roofs suggests enhanced copper release through corrosion and prolonged interaction between rainfall and roofing surfaces.

Previous studies (Despins *et al.*, 2009) have reported that metallic roofing materials can contribute appreciable concentrations of trace metals to harvested rainwater through surface degradation and runoff processes,

In contrast, nickel was not detected in any of the rainwater samples irrespective of roofing type or age. The absence of detectable nickel suggests that the roofing materials investigated are not significant sources of nickel contamination and that atmospheric deposition of nickel within the study area was minimal during the sampling period.

The results indicate that prolonged use of metallic roofing sheets promotes the accumulation of potentially toxic metals in harvested rainwater. The increases in cadmium, lead, arsenic, and copper with roofing age highlight the importance of routine monitoring and appropriate treatment of harvested rainwater intended for domestic consumption. The findings further suggest that roof age should be considered an important factor in rainwater quality assessment and management.

## Conclusion

This study demonstrated that the type and age of roofing materials significantly affect the levels of heavy metal contamination in harvested rainwater. The findings suggest that prolonged use of metallic roofing sheets can compromise the quality of harvested rainwater and may pose potential health risks when such water is consumed without treatment. Therefore, routine monitoring of roof-harvested rainwater, periodic maintenance or replacement of ageing roofing materials, and appropriate water treatment measures are recommended to ensure the safety of harvested rainwater for domestic use.

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**CITATION** Akwagiobe EU, Uboh FE, Godwin EE (2026 Heavy Metal Contamination in Roof-Harvested Rainwater from Different Roofing Materials in Calabar Metropolis, Nigeria  
Trend Nat Prod Res Vol 7(4) 347-354. <https://doi.org/10.61594/tnpr.v7i4.2026.181>