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***Research Article***

# Health Risk Assessment of heavy metal contaminated Groundwater in Tertiary Institutions in Rivers State

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**Abstract**

Heavy metals contamination of groundwater poses serious public health risks due to their toxic and carcinogenic effects. This study evaluated the health risks associated with heavy metal contamination in groundwater from public universities in Rivers State, Nigeria. Groundwater samples were collected from Rivers State University (RSU), Ignatius Ajuru University (IAU), and the University of Port Harcourt (UNIPORT) and analyzed for lead (Pb), cadmium (Cd), chromium (Cr), and iron (Fe) using Atomic Absorption Spectrophotometry. The Heavy Metal Pollution Index (HPI), non-carcinogenic risks, and carcinogenic risks were assessed. Results revealed widespread contamination, with concentrations consistently exceeding WHO and Nigerian Industrial Standards (NIS) limits. Pb (0.020–0.120 mg/L) and Cd (0.026–0.198 mg/L) were particularly elevated, while Cr (0.007–0.074 mg/L) and Fe (0.607–1.286 mg/L) also exceeded permissible levels. HPI values were all greater than 100, indicative of high contamination of heavy metals in the groundwater. Non-carcinogenic risk assessments showed Hazard Quotient (HQ) values for Pb and Cd far above the acceptable risk limit of 1. Similarly, Hazard Index (HI) values was greater than 1, indicating significant cumulative health risks. Carcinogenic risk values for Cd and Cr exceeded acceptable thresholds, suggesting cancer risk. Principal Component Analysis and hierarchical cluster confirmed distinct pollution sources contributing to the observed contamination patterns. These findings show considerable public health risks from heavy metal contamination in groundwater across the study sites. Immediate interventions, including regular monitoring, improved water treatment, and stricter water quality management strategies, are urgently required to safeguard the health of university communities in Rivers State.

## 1. Introduction

Heavy metals, such as lead (Pb), cadmium (Cd), chromium (Cr), and iron (Fe), are persistent environmental contaminants of global concern due to their non-biodegradable nature and tendency to bioaccumulate in living systems. Chronic exposure to these metals has been associated with serious health outcomes, including neurotoxicity, nephrotoxicity, reproductive toxicity, and carcinogenicity [1, 2]. Unlike organic pollutants, heavy metals do not degrade naturally, and even trace concentrations in water sources can accumulate to levels that pose significant risks to human health. Groundwater contamination by heavy metals often results from industrial discharges, oil exploration and refining activities, agricultural runoff, leaching from waste disposal sites, and natural geochemical processes [3, 4]. In Rivers State, Nigeria, the

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extensive oil and gas activities exacerbate the risk of groundwater pollution, with several studies reporting elevated concentrations of heavy metals in both surface and groundwater that exceed permissible limits set by the World Health Organization (WHO) and Nigerian Industrial Standards (NIS). Moreover, a study reported elevated level of heavy metals in soils and vegetables in tertiary institutions in Rivers State, that posed health risk to humans that consumed the heavy metal contaminated vegetables as well as posed severe ecological risk [5].

Tertiary institutions, such as universities, are particularly vulnerable to the consequences of poor water quality. Large campus populations depend heavily on available groundwater for drinking, cooking, and sanitation. Inadequate infrastructure, insufficient treatment facilities, and weak regulatory oversight increase the likelihood of exposure to unsafe water. This raises concerns about the health of students, staff, and visitors who rely on these sources for their daily needs. Despite the increasing evidence of heavy metal contamination in Nigeria, limited research has specifically examined groundwater quality in universities within Rivers State, leaving a critical knowledge gap. Addressing this gap is essential for safeguarding public health and informing water management strategies. This study therefore aims to assess the concentrations of selected heavy metals (Pb, Cd, Cr, and Fe) in groundwater from three public universities in Rivers State, Nigeria, and to evaluate the associated non-carcinogenic and carcinogenic health risks.

## 2. Materials and Methods

### 2.1. Study Design

This study employed a laboratory-based experimental design using a Completely Randomized Design (CRD) to assess the concentrations of selected heavy metals in groundwater and their associated health risks. The analysis focused on lead (Pb), cadmium (Cd), chromium (Cr), and iron (Fe), with risk assessment conducted for both non-carcinogenic and carcinogenic effects.

### 2.2. Study Area

The study was conducted in three public universities located in Rivers State, Nigeria: Rivers State University (Latitude: 4.800974, Longitude: 6.982289), the University of Port Harcourt (Latitude: 4.907361, Longitude: 6.922251), and Ignatius Ajuru University of Education (Latitude: 4.806478, Longitude: 6.931471). Groundwater samples were collected from drinking water sources within these institutions for laboratory analysis of heavy metal concentrations.

### 2.3. Sample Collection

This study was conducted during October and November 2024, a period characterized by minimal rainfall, which ensured stable groundwater conditions. Groundwater samples were collected from eight randomly selected boreholes across three public universities in Rivers State, Nigeria. At each sampling location, 500 mL of water was collected using sterile polyethylene bottles, following the procedures outlined by the American Public Health Association [6]. Prior to grab sampling, each borehole was flushed for 2 minutes to remove stagnant water, and the bottles were rinsed twice with the flushed water to minimize contamination. Samples were immediately preserved on ice in a cooler box and transported to the laboratory at Rivers State University for analysis.

### 2.4. Heavy Metal Analysis

Heavy metal concentrations were determined using an Agilent FS240AA Atomic Absorption Spectrophotometer, following the method described by [6].

### 2.5. Sample Digestion

Five milli liter (5 mL) of the water sample were measured and transferred into a digestion flask. Then, 20ml of an acid mixture (comprising 650ml concentrated $HNO_3$, 80ml perchloric acid, and 20ml concentrated $H_2SO_4$) was added. The mixture was heated in the digestion flask until a clear solution was obtained. The digest was then diluted with distilled water to a final volume of 50ml.

### 2.6. Instrument Calibration and Analysis

The Atomic Absorption Spectrophotometer (Agilent FS240AA) was calibrated using certified reference standards for each target metal. Calibration standards were prepared to cover the expected concentration range of the analytes. Instrument settings, including lamp current, slit width, and flame type, were optimized according to the manufacturer's specifications for each element.

For analysis, a 5 mL aliquot of each digested sample was aspirated into the spectrophotometer, and absorbance was measured at the characteristic wavelengths of the respective metals. The concentrations of Pb, Cd, Cr, and Zn were quantified by comparing absorbance values with calibration curves generated from the standards.

To ensure accuracy and precision, quality control procedures included the analysis of reagent blanks, spiked samples, duplicate samples, and Certified Reference Materials (CRMs). All determinations were performed in triplicate, and the results were expressed in milligrams per liter (mg/L).

### 2.7. Heavy Metal Pollution Index (HPI)

The degree of groundwater contamination was evaluated using the Heavy Metal Pollution Index (HPI). The standard permissible values (Si) and ideal values (Ii) for each metal were obtained from the World Health Organization.
The HPI was computed using Equation 1.

$$HPI = \sum i = 1nWi \sum i = 1nWi \times Qi \tag{1}$$

where

- Wi = unit weight of the ith parameter,
- Qi = sub-index of the ith parameter,
- n = number of parameters considered.

The sub-index (Qi) for each parameter was calculated using Equation 2.

$$Qi = \frac{(Mi - Ii)}{(Si–Ii) \times 100} \tag{2}$$

where

- Mi = measured concentration of the ith parameter (ppb),
- Si = standard permissible value (ppb),
- Ii = ideal value (ppb).

According to HPI classification, groundwater is considered non-contaminated when the index value is less than 100, while an HPI greater than 100 indicates contamination.

## 2.8. Health Risk Assessment

Health risks associated with groundwater consumption were assessed following the United States Environmental Protection Agency [7] guidelines, considering both non-carcinogenic and carcinogenic effects.

## 2.9. Non-Carcinogenic Risk

Non-carcinogenic risk was evaluated using the Chronic Daily Intake (CDI) and Hazard Quotient (HQ).
The CDI was calculated using Equation 3.

$$CDI = \frac{Cgw \times IR \times EF \times ED}{AT \times BW} \tag{3}$$

where

- Cgw is the average concentration of heavy metals in water (mg/L),
- IR is the ingestion rate (2.0 L/day for adults; 1.0 L/day for children),
- EF is the exposure frequency (365 days/year),
- ED is the exposure duration (70 years for adults; 10 years for children),
- AT is the average time (25,550 days for adults; 3,650 days for children), and
- BW is body weight (70 kg for adults; 30 kg for children).

The HQ was derived using Equation 4.

$$HQ = \frac{CDI}{RfD} \tag{4}$$

where

- RfD is the oral reference dose (mg/kg/day).

The RfD values applied were $Cd(1.0 \times 10^{-3})$, Cr $(3.0 \times 10^{-3})$, Fe (0.7), Pb $(3.6 \times 10^{-3})$, Zn $(3.0 \times 10^{-1})$, Mn $(1.4 \times 10^{-1})$, Cu $(3.7 \times 10^{-2})$, and V $(7.0 \times 10^{-3)}$. An $HQ < 1$ suggests negligible risk, while $HQ > 1$ indicates potential adverse effects. The cumulative non-carcinogenic risk was assessed using the Hazard Index (HI), the sum of HQs for all metals.

## 2.10. Carcinogenic Risk

Carcinogenic risk (CR) was assessed for cadmium (Cd), chromium (Cr), and lead (Pb), which are classified as Group 1 human carcinogens by the International Agency for Research on Cancer [8].
The CR was estimated using Equation 5.

$$CR = CDI \times SF \tag{5}$$

where

- CDI = chronic daily intake (mg/kg/day),
- SF = slope factor (kg/day/mg).

The slope factors applied were:

- Cd: 0.38,
- Cr: 0.50,
- Pb: $8.510^{-3}$ [9].

The total carcinogenic risk (CT) was obtained as the sum of individual risks Equation 6.

$$CT = CR_{cd} + CR_{cr} + CR_{bp} \tag{6}$$

Risk interpretation was based on U.S. EPA guidelines:

- CR or $CT < 1 \times 10^{-6}$: negligible carcinogenic risk,
- $1 \times 10^{-6}$ 1 to $1 \times 10^{-4}$: acceptable/tolerable risk range,
- CR or $CT > 1 \times 10^{-4}$: unacceptable carcinogenic risk.

### 2.11. Data Analysis

Experimental measurements were conducted in duplicates, and results were expressed as mean ± standard deviation (SD). Statistical analyses were performed to evaluate the significance of the parameters studied. To identify potential sources and grouping patterns of heavy metals, multivariate statistical analyses were performed. Principal Component Analysis (PCA) was used to reduce dimensionality and determine the major contributing factors, with components having eigenvalues $> 1$ extracted for interpretation. Hierarchical Cluster Analysis (HCA) was conducted using Euclidean distance as the similarity measure and Ward's minimum variance method as the linkage criterion to classify sampling sites based on similarity in heavy metal distribution. Both PCA and HCA were carried out in Origin Pro 2024b.

### 2.12. Ethical Considerations

Ethical approval was obtained from the relevant institutional review board prior to the commencement of data collection activities.

## 3. Results

Table 1 showed that Lead (0.051–0.088 mg/L), cadmium (0.026–0.060 mg/L), and iron (0.607–0.950 mg/L) concentrations exceeded permissible limits, while chromium (0.018–0.037 mg/L) remained below but close to the threshold. Hazard quotients for Pb (4.87–8.40) and Cd (1.49–3.44) were above 1, resulting in hazard index values (8.47–10.84) that indicated significant cumulative non-carcinogenic risks Table 2. Carcinogenic risks were highest for Cd ($4.69 \times 10^{-2}$–$1.08 \times 10^{-1}$) and Cr ($2.58 \times 10^{-4}$–$5.29 \times 10^{-4}$), both far above acceptable limits, while Pb ($1.24 \times 10^{-5}$–$2.14 \times 10^{-5}$) was within or slightly above the threshold Table 3. Overall, the cumulative cancer risk exceeded $1 \times 10^{-4}$, signifying substantial long-term health concerns.

**Table 1:** Heavy Metal Concentrations of Groundwater from Rivers State University (RSU)

| Sample location | Pb (mg/L) | Cd (mg/L) | Cr (mg/L) | Fe (mg/L) |
|---|---|---|---|---|
| RSU Site 1 | 0.069±0.003 | 0.026±0.003 | 0.036±0.002 | 0.607±0.004 |
| RSU Site 2 | 0.051±0.002 | 0.06±0.002 | 0.037±0.003 | 0.746±0.003 |
| RSU Site 3 | 0.088±0.002 | 0.038±0.004 | 0.018±0.003 | 0.95±0.003 |
| WHO | 0.01 | 0.003 | 0.05 | 0.3 |
| NIS | 0.01 | 0.003 | 0.01 | 0.3 |

Key: WHO- World Health Organization, NIS- Nigerian Industrial Standard

**Table 2:** Non-Cancer Risk Assessment of Heavy metals Concentrations of Groundwater from Rivers State University (RSU)

| Location | HPI | HQ (Pb) | HQ (Cd) | HQ(Cr) | HQ(Fe) | HI |
|---|---|---|---|---|---|---|
| RSU Site 1 | 457.75 | 6.58 | 1.49 | 0.34 | 0.06 | 8.47 |
| RSU Site 2 | 708.17 | 4.87 | 3.44 | 0.35 | 0.07 | 8.73 |
| RSU Site 3 | 624.83 | 8.40 | 2.18 | 0.17 | 0.09 | 10.84 |

**Table 3:** Cancer Risk Assessment of Heavy Metals Concentrations of Groundwater from Rivers State University (RSU)

| Location | CR (Pb) | CR (Cd) | CR (Cr) |
|---|---|---|---|
| RSU Site 1 | $1.68 \times 10^{-5}$ | $4.69 \times 10^{-2}$ | $5.15 \times 10^{-4}$ |
| RSU Site 2 | $1.24 \times 10^{-5}$ | $1.08 \times 10^{-1}$ | $5.29 \times 10^{-4}$ |
| RSU Site 3 | $2.14 \times 10^{-5}$ | $6.85 \times 10^{-2}$ | $2.58 \times 10^{-4}$ |

The concentrations of Pb, Cd, Cr, and Fe in groundwater samples from Ignatius Ajuru University are presented in Table 4. Lead ranged from 0.044–0.120 mg/L, with the highest concentration recorded at the IAU Site 3 (0.120 ± 0.014 mg/L), which is more than ten times the WHO/NIS guideline value of 0.01 mg/L. Cadmium varied between 0.064–0.172 mg/L, far above the permissible limit of 0.003 mg/L. Chromium ranged from 0.007–0.074 mg/L, exceeding the standard limit of 0.05 mg/L at the IAU Site 3 (0.074 ± 0.003 mg/L). Iron concentrations were consistently high (0.740–1.000 mg/L), surpassing the WHO/NIS limit of 0.3 mg/L across all sites. These findings indicate severe contamination of groundwater with toxic heavy metals.

The non-carcinogenic risk indices are shown in Table 5. Hazard Quotient (HQ) values for Pb (4.59–11.45) and Cd (2.14–9.85) were consistently greater than 1 across all sites, indicating significant non-carcinogenic risks. Chromium (HQ = 0.07–0.71) and iron (HQ = 0.07–0.10) presented lower risks individually. However, cumulative Hazard Index (HI) values exceeded unity at all locations, with the highest value (15.89) at the IAU Site 3.

**Table 4:** Heavy Metal Concentrations of Groundwater from Ignatius Ajuru University (IAU)

| Sample location | Pb (mg/L) | Cd (mg/L) | Cr (mg/L) | Fe (mg/L) |
|---|---|---|---|---|
| IAU Site 1 | 0.059±0.003 | 0.09±0.001 | 0.007±0.001 | 0.972±0.035 |
| IAU Site 2 | 0.044±0.006 | 0.172±0.004 | 0.019±0.001 | 1±0.0001 |
| IAU Site 3 | 0.12±0.014 | 0.064±0.004 | 0.074±0.003 | 0.74±0.002 |
| WHO | 0.01 | 0.003 | 0.05 | 0.3 |
| NIS | 0.01 | 0.003 | 0.01 | 0.3 |

Key: WHO- World Health Organization, NIS- Nigerian Industrial Standard

**Table 5:** Non-Cancer Risk Assessment of Heavy Metals Concentration from Ignatius Ajuru University (IAU)

| Location | HPI | HQ (Pb) | HQ (Cd) | HQ(Cr) | HQ(Fe) | HI |
|---|---|---|---|---|---|---|
| IAU Site 1 | 882.00 | 5.63 | 5.15 | 0.07 | 0.09 | 10.94 |
| IAU Site 2 | 1536.17 | 4.19 | 9.85 | 0.18 | 0.10 | 14.32 |
| IAU Site 3 | 832.00 | 11.45 | 3.66 | 0.71 | 0.07 | 15.89 |

Carcinogenic risk values are summarized in Table 6. Cadmium showed the highest cancer risk across all sites, ranging from $1.15 \times 10^{-1}$ – $3.10 \times 10^{-1}$, which are several orders of magnitude higher than the acceptable USEPA range $(1 \times 10^{-6}$–$1 \times 10^{-4})$. Chromium also exceeded safe limits, with the highest value $(1.06 \times 10^{-3})$ recorded at the IAU Site 3. Lead presented lower risks $(1.07 \times 10^{-5}$–$2.92 \times 10^{-5})$, but these still fall within or slightly above the unsafe range.

**Table 6:** Cancer Risk Assessment of Heavy Metals Concentrations of Groundwater from Ignatius Ajuru University (IAU)

| Location | CR (Pb) | CR (Cd) | CR (Cr) |
|---|---|---|---|
| IAU Site 1 | $1.44 \times 10^{-5}$ | $1.62 \times 10^{-1}$ | $1.00 \times 10^{-4}$ |
| IAU Site 2 | $1.07 \times 10^{-5}$ | $3.10 \times 10^{-1}$ | $2.72 \times 10^{-4}$ |
| IAU Site 3 | $2.92 \times 10^{-5}$ | $1.15 \times 10^{-1}$ | $1.06 \times 10^{-3}$ |

The heavy metal concentrations of groundwater samples from the University of Port Harcourt Table 7 showed varying levels of lead (Pb), cadmium (Cd), chromium (Cr), and iron (Fe) across different sampling points. Lead concentrations ranged from 0.02 mg/L at UP Site 1 to 0.095 mg/L at UP Site 2. All the recorded Pb values exceeded the WHO and NIS permissible limit of 0.01 mg/L, indicating significant contamination. Cadmium levels were highest at UP Site 3 (0.198 mg/L) and lowest at UP Site 1 (0.054 mg/L), with all values surpassing the guideline limit of 0.003 mg/L, showing potential health concerns. Chromium concentrations varied between 0.018–0.066 mg/L, also exceeding the permissible limit of 0.05 mg/L at UP Site 3. Iron levels ranged from 0.649 mg/L at UP Site 3 to 1.286 mg/L at UP Site, which were consistently higher than the WHO/NIS standard of 0.3 mg/L.

**Table 7:** Heavy Metal Concentrations of Groundwater from University of Port Harcourt (Uniport)

| Sample location | Pb (mg/L) | Cd (mg/L) | Cr (mg/L) | Fe (mg/L) |
|---|---|---|---|---|
| UP Site 1 | 0.02±0.001 | 0.054±0.004 | 0.018±0.003 | 1.286±0.004 |
| UP Site 2 | 0.095±0.002 | 0.188±0.002 | 0.037±0.004 | 0.887±0.004 |
| UP Site 3 | 0.085±0.021 | 0.198±0.0001 | 0.066±0.005 | 0.649±0.002 |
| WHO | 0.01 | 0.003 | 0.05 | 0.3 |
| NIS | 0.01 | 0.003 | 0.01 | 0.3 |

Key: WHO- World Health Organization, NIS- Nigerian Industrial Standard

The non-cancer risk assessment Table 8 showed high hazard quotient (HQ) values for Pb and Cd, particularly at UP Site 2 (HQ for Pb = 9.07, Cd = 10.76) and UP Site 3 (Pb = 8.11, Cd = 11.34). The hazard index (HI), which represents cumulative risk, exceeded the safe threshold of 1 at all locations, with the highest values observed at UP Site 2 (20.26) and UP Site 3 (20.14).

**Table 8:** Non-Cancer Risk Assessment of Heavy Metals Concentrations of Groundwater from University of Port Harcourt (Uniport)

| Location | HPI | HQ (Pb) | HQ (Cd) | HQ (Cr) | HQ (Fe) | HI |
|---|---|---|---|---|---|---|
| UP Site 1 | 735.00 | 1.91 | 3.09 | 0.17 | 0.12 | 5.29 |
| UP Site 2 | 2418.50 | 9.07 | 10.76 | 0.35 | 0.08 | 20.26 |
| UP Site 3 | 2501.50 | 8.11 | 11.34 | 0.63 | 0.06 | 20.14 |

The cancer risk assessment Table 9 revealed significant carcinogenic potentials, particularly from cadmium and chromium exposure. At UP Site 2, cadmium recorded a cancer risk of $3.39 \times 10^{-1}$, while chromium reached $5.29 \times 10^{-4}$, both far above the acceptable risk threshold of $1 \times 10^{-6}$to$1 \times 10^{-4}$ recommended by regulatory agencies. Similarly, at UP Site 3, chromium posed the highest cancer risk $(9.45 \times 10^{-4})$, indicating alarming levels of potential long-term health effects.

Pearson correlation analysis in Table 10 reveals the relationships between heavy metal concentrations in the water samples.

Lead (Pb) and Chromium (Cr) exhibit a statistically significant positive correlation (r = 0.673, p = 0.047), indicating that as Pb concentration increases, Cr concentration tends to increase as well. Lead (Pb) and Iron (Fe) show a moderate negative correlation (r =

**Table 9:** Cancer Risk Assessment of Heavy Metals Concentrations of Groundwater from University of Port Harcourt (Uniport)

| Location | CR (Pb) | CR (cd) | CR (cr) |
|---|---|---|---|
| UP Site 1 | $4.87 \times 10^{-5}$ | $9.74 \times 10^{-2}$ | $2.58 \times 10^{-4}$ |
| UP Site 2 | $2.31 \times 10^{-5}$ | $3.39 \times 10^{-1}$ | $5.29 \times 10^{-4}$ |
| UP Site 3 | $2.07 \times 10^{-5}$ | $3.57 \times 10^{-1}$ | $9.45 \times 10^{-4}$ |

-0.598, p = 0.089), though not statistically significant. This might suggest that higher Pb concentrations are associated with lower Fe levels, potentially due to competitive interactions in the water matrix.

Chromium (Cr) and Iron (Fe) also have a statistically significant negative correlation (r = -0.672, p = 0.047), implying that areas with higher Cr contamination tend to have lower Fe levels. Cadmium (Cd) shows weak correlations with other metals, with none being statistically significant. This indicates that Cd contamination is likely independent of Pb, Cr, and Fe, possibly originating from different sources.

**Table 10:** Pearson correlation coefficient of the selected parameters

| Variable | Pb (mg/L) | Cd (mg/L) | Cr (mg/L) | Fe (mg/L) |
|---|---|---|---|---|
| 1. Pb (mg/L) | — | | | |
| | — | | | |
| 2. Cd (mg/L) | 0.129 | — | | |
| | 0.740 | — | | |
| 3. Cr (mg/L) | 0.673 * | 0.212 | — | |
| | 0.047 | 0.583 | — | |
| 4. Fe (mg/L) | -0.598 | -0.059 | -0.672 * | — |
| | 0.089 | 0.880 | 0.047 | — |

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

The Principal Component Analysis (PCA) are shown in Figures 1 and 2.

The Eigenvalues and percentage variance explain the contribution of each principal component (PC) to the total variation in heavy metal concentrations. PC1 (58.44%) represents the most significant variation in the dataset, likely driven by Pb, Cr, and Fe, given their correlations. PC2 (24.39%) contributes additional variance, which may be influenced by Cd.

The cumulative variance of 82.83% for the first two PCs suggests that most of the variation in heavy metal concentrations is captured by these two principal components, making them suitable for explaining pollution patterns.

The bioplot Figure 2 visually represents the sampling sites and their pollution levels based on PC1 and PC2. Sites located far from the origin are more polluted compared to those clustered near the center.

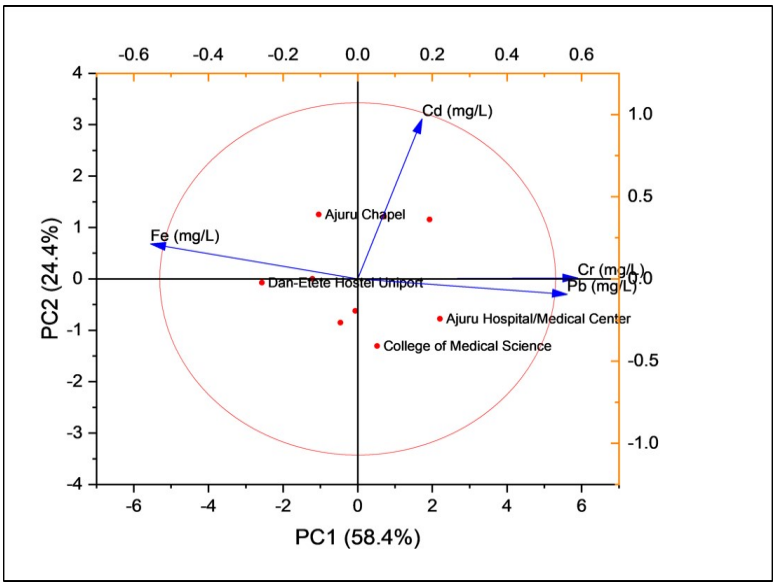


**Figure 1:** Bioplot of the main two PCs showing the site of Pollution

| Principal Component Number | Eigenvalue | Percentage of Variance (%) | Cumulative (%) |
|---|---|---|---|
| 1 | 2.33741 | 58.43525 | 58.43525 |
| 2 | 0.97579 | 24.39485 | 82.8301 |
| 3 | 0.39781 | 9.94516 | 92.77526 |
| 4 | 0.28899 | 7.22474 | 100 |

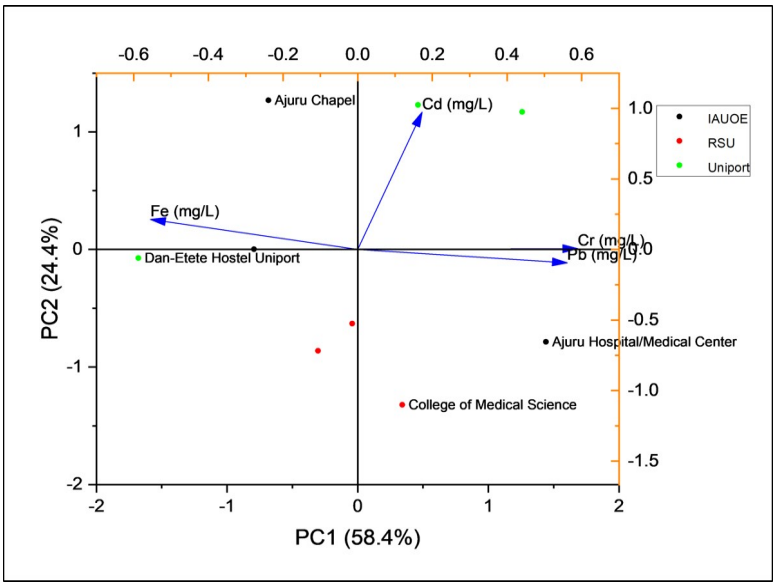


**Figure 2:** Bioplot of the two main PCs showing the site of Pollution

Figure 3 shows the Dendrogram of Sampling Sites. The clustering of sampling sites suggests similarities in contamination levels. Sites grouped closely together likely share common pollution sources, while those in separate clusters may have different contamination profiles.

Figure 4 shows (Dendrogram of Heavy Metals). This clustering reveals associations among metals. For instance, if Pb and Cr cluster together. Conversely, if Cd forms a separate cluster, it further confirms its distinct contamination source.

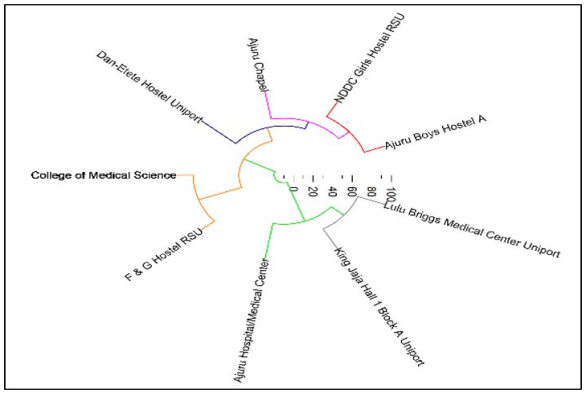


**Figure 3:** Dendrogram illustrating the clustering of sampling sites of the groundwater

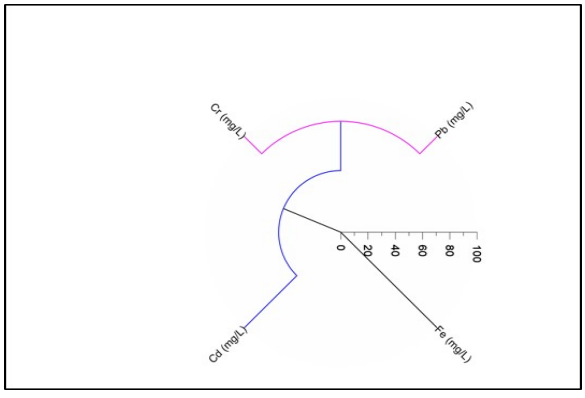


**Figure 4:** Dendrogram illustrating the Clustering of the Heavy Metals in the Groundwater

## 4. Discussion

Groundwater contamination by heavy metals is a critical environmental and public health concern, particularly in developing countries where reliance on untreated groundwater is high. This study showed substantial contamination of groundwater sources in three public universities in Rivers State, Nigeria, Rivers State University (RSU), Ignatius Ajuru University (IAU), and the University of Port Harcourt (Uniport), with lead (Pb), cadmium (Cd), chromium (Cr), and iron (Fe). The findings highlight the vulnerability of institutional water supplies to anthropogenic pollution and the potential health risks to students, staff, and surrounding communities [10, 11].

At RSU, concentrations of Pb and Cd consistently exceeded permissible limits, raising serious health concerns. Lead exposure is well documented for its neurotoxic, cardiovascular, renal, and reproductive effects even at low doses [12, 13], while cadmium is nephrotoxic, osteotoxic, and classified as a Group 1 human carcinogen [14, 15]. Elevated levels in student hostels suggest heightened risk through daily consumption of contaminated water. Possible contamination pathways include corroded plumbing systems, leaching from nearby dumpsites, and industrial discharges associated with Port Harcourt's oil-related activities [16].

Similarly, groundwater from IAU exhibited high concentrations of Pb, Cd, and Cr, particularly around the IAU Site 3 and 2. Chromium, especially in its hexavalent form [Cr (VI)], is highly toxic and linked to carcinogenesis, hepatotoxicity, and dermatological disorders [9]. The co-occurrence of multiple heavy metals at these sites indicates mixed sources of contamination, including industrial runoff, improper waste management, and geogenic contributions. Iron levels were also elevated, reducing water acceptability and potentially contributing to chronic conditions such as cirrhosis, diabetes, and oxidative stress [17].

At Uniport, groundwater samples from Site 3 contained elevated levels of all four metals, posing compounded risks. The presence of multiple contaminants in a Site 3 facility is particularly troubling, as safe water is essential for patient care and hygiene. Co-exposure to Pb and Cd is known to exacerbate nephrotoxicity and cardiovascular dysfunction, highlighting the synergistic risks of mixed-metal contamination [18].

Beyond concentration data, the Heavy Metal Pollution Index (HPI) and overall water quality index placed groundwater across the three universities within the "poor" to "unfit for drinking" categories. These integrative indices, widely used in water quality assessment, reinforce the severity of contamination. Risk assessment further demonstrated that hazard quotients (HQ) for Pb and Cd were well above 1, indicating significant non-carcinogenic risks, while cancer risk values for Cd and Cr exceeded the USEPA's acceptable threshold ($1 \times 10^{-6}$–$1 \times 10^{-4}$), confirming the carcinogenic burden of chronic groundwater consumption [19].

These findings are consistent with prior studies in Port Harcourt and other Nigerian cities. [20, 21] reported elevated Pb and Cd in urban water sources, attributing contamination to oil refining, industrial effluents, and indiscriminate waste dumping. Also documented the susceptibility of institutional water supplies in Nigeria to pollution due to poor infrastructure and weak regulatory enforcement. Thus, the present results reflect a wider environmental challenge rather than isolated cases.

The socio-economic implications are significant. Unsafe water in universities can contribute to recurrent waterborne disease outbreaks, impaired academic performance, and increased long-term healthcare costs. Furthermore, reliance on sachet and bottled water as alternatives imposes financial strain on students, many of whom face economic hardship.

Multivariate analyses provided further insight into contamination sources. Pearson correlation revealed a strong positive association between Pb and Cr ($r = 0.673$, $p < 0.05$), suggesting shared sources such as industrial effluents or corroded infrastructure [13]. Conversely, the negative correlation between Pb and Fe may reflect differential geochemical mobilization processes [22]. Principal Component Analysis (PCA) identified Pb, Cr, and Fe as dominant contributors to groundwater variability, indicating mixed anthropogenic and geogenic influences [23]. Hierarchical clustering grouped sites with similar contamination profiles, further pointing to localized pollution hotspots.

Overall, this study highlights the urgent need for intervention. Regular groundwater monitoring should be institutionalized across Nigerian universities. Treatment technologies such as activated carbon filtration, ion-exchange, and reverse osmosis should be deployed to reduce heavy metal loads to safe levels. At a policy level, stricter enforcement of waste management and industrial discharge regulations is imperative. Targeted public health campaigns are also needed to sensitize students and staff to the risks of consuming untreated groundwater.

### Uncertainty Analysis of Health Risk

All risk estimations methods involve some degree of uncertainty that exists at several levels. The two primary sources of uncertainty in the assessment of human exposures to pollutants include the concentrations of the assessed pollutants to which the potential population may be exposed all through the exposure period and ambiguity about the exposed population [24, 25]. In this present study, both of these influenced the result significantly. The real exposed population could not be studied; thus, the health risk was based exclusively on hypothetical exposure scenarios. Consequently, uncertainty in the results obtained may be significant. Besides, uncertainty in dose-response of both noncarcinogenic and carcinogenic data was also a contributory factor. The reference dose values employed herein have uncertainty factors of 1 or 2 orders of magnitude. The various assumptions used in this study, such as the lifetime of 70 years, bodyweight of 70 kg for adults, increase the uncertainties involved in the assessment process. Thus, the results provided in this work are simply an indication of the potential health risk associated with potential exposure to heavy metals contaminated groundwater, if used for drinking and bathing purposes. It is likely that these risks predicted may be an underestimation of the actual health risks as they only portray the risks associated with a population exposed to the selected heavy metals in this work. Several other pollutants including other heavy metals were not considered in this present study; nevertheless, the likelihood of the occurrence of other pollutants that are injurious to humans in the investigated groundwater samples is high. Therefore, a health risk may be higher than what is represented in this paper.

## 5. Conclusion

This study showed that groundwater from RSU, IAU, and Uniport are contaminated with Pb, Cd, and Fe at levels exceeding WHO guidelines, posing serious non-carcinogenic and carcinogenic health risks. By combining heavy metal analysis with risk assessment models, the study shows the contamination levels of groundwater samples in the investigated tertiary institutions and their implications for public health. Urgent interventions including improved water treatment, infrastructure upgrades, stricter waste management, routine monitoring, and strengthened policy enforcement are essential to safeguard groundwater quality. Public awareness campaigns are also critical to reduce

reliance on untreated water and mitigate long-term health risks.

### Article Information

**Disclaimer (Artificial Intelligence):** The author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.), and text-to-image generators have been used during writing or editing of manuscripts.

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