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POTENTIAL TOXIC METALS (PTMs) POLLUTION OF UNDERGROUND WATER (WELL WATER) IN IJORA - BADIA AREA OF LAGOS STATE, SOUTHWESTERN NIGERIA

***[1]Ojiodu, Chukwuwuba Chekwube, [2]Eruola, Adeyinka Olubunmi, [3]Olumayede, Emmanuel Gbenga, [1]Moses, Donatus Ugochukwu, [4]Ikegwu, Emmanuel Mmaduabuchi and [5]Ashiru, Abiodun Waidi**

[1]College Central Research Laboratory, Yaba College of Technology, Yaba, Lagos State, Nigeria.
[2]Department of Chemical Sciences, Yaba College of Technology, Yaba, Lagos State, Nigeria.
[3]Department of Industrial Chemistry, Federal University, Oye, Ekiti State, Nigeria.
[4]Department of Statistics, Yaba College of Technology, Yaba, Lagos State, Nigeria.
[5]Department of Biological Sciences, Yaba College of Technology, Yaba, Lagos State, Nigeria.

*Corresponding authors' email: ojioducc@yahoo.com Phone: +2348138335470

ABSTRACT

Inadequate public water supply in Ijora-Badia forces groundwater dependence, raising concerns about potentially toxic metal contamination and public health risks. This study presents Potential Toxic Metals (PTMs) Pollution of Undergroundwater(wellwater) in Ijora - Badia Area of Lagos - State, Southwestern-Nigeria**.** Ten well - water samples were randomly collected from ten different locations, four times per month from August 2024 to January 2025. Samples were collected using pre-washed, labeled plastic containers, digested, and analyzed for PTMs - Pb, Cd, Cr, As, and Hg using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP - OES). Results showed variations in PTMs concentrations across sampling locations whose ranges included Hg - (0.0008 - 0.0139 mg/L), Pb - (0.0244 - 0.9269 mg/L), Cd - (0.0014 -0.0192 mg/L), As - (0.0035 - 0.0809 mg/L), and Cr - (0.0025 - 0.4175 mg/L). Lead-(19.0482 mg/L) recorded the highest concentration whereas mercury - (0.0513 mg/L) showed the lowest. ISIB (9.4056 mg/L; 45.6%) was the most heavily polluted site, while CS (0.0485 mg/L; 0.2%) showed minimal contamination. The distribution trend of PTMs followed the order Pb > Cr > As > Cd > Hg. Principal Component Analysis identified a single dominant component (PC1) accounting for 86.45% of the total variance, suggesting predominantly anthropogenic Sources. Heavy Metal Pollution Index (HPI), Metal Index (MI), and Pollution Index (PI) all confirm severe contamination. Correlation results ($p > 0.5$) further reinforced the high pollution burden. PTM levels exceeded Nigeria Industrial Standards (NIS) and WHO guidelines, rendering the groundwater unsafe for domestic use.

Keywords: Toxic, Metals, Anthropogenic, Groundwater, Environment, Significant

INTRODUCTION

The inability of Federal, State, and Local Governments, particularly the Lagos State Water Corporation (LWC), to provide sufficient potable water has compelled residents of Ijora - Badia, Lagos State, to rely heavily on groundwater sources, including wells (Abraham *et al.,* 2021). Water, a transparent, tasteless, nearly colorless inorganic substance, is essential for life and socio-economic development, covering approximately 70.9% of the Earth's surface (Scott *et al.,* 2019; Indri *et al.,* 2023). It exists mainly as groundwater and surface water, with groundwater encompassing wells, springs, and boreholes, while surface water includes streams, wetlands, creeks, and reservoirs (Emenike *et al.,* 2019). In areas with limited water infrastructure, such as developing countries and communities like Ijora - Badia, groundwater remains a critical resource for domestic use, agriculture, and livestock, highlighting the need for regular monitoring and sustainable management (UNICEF and WHO, 2021; Rahman *et al.,* 2020).

Potentially toxic metals (PTMs) are metallic and metalloid elements that can pose significant threats to living organisms, even at trace concentrations. Notable PTMs include lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), chromium (Cr), nickel (Ni), copper (Cu), zinc (Zn), manganese (Mn), and cobalt (Co) (Olusola *et al.,* 2023; Valko *et al.,* 2024). These elements are highly persistent, non-biodegradable, and prone to bioaccumulation and biomagnification along food chains, thereby amplifying their toxic effects in ecosystems (Satarug *et al.,* 2022). PTMs are introduced into the environment through both natural and human - induced processes. Natural sources include rock weathering, volcanic eruptions, erosion, and leaching from mineral deposits (Badamasi *et al.,* 2023), whereas anthropogenic sources involve mining, smelting, industrial effluents, fossil fuel combustion, improper waste disposal, and agricultural practices (Ali *et al.,* 2025; Ezeajughu and Ezeajughu, 2024; Singh and Kumar, 2024). Humans are exposed via ingestion, inhalation, dermal contact, occupational activities, dietary intake, and maternal - fetal transfer (Zhang *et al.,* 2024; Valko *et al.,* 2024). Consumption of PTM - contaminated water above safe limits can result in acute or chronic health effects, including neurotoxicity, organ damage, and cancer (WHO, 2022; Jaishankar *et al.,* 2014). Analytical techniques such as ICP-MS, FAAS, and GF - AAS are employed to measure PTM levels (Faisal *et al.,* 2014; Behailu *et al.,* 2017).

Ijora - Badia, situated on the Lagos Mainland in southwestern Nigeria, is a densely populated settlement positioned close to major Nigeria railway corridors, where many residents live in congested and substandard conditions. The community faces severe infrastructural deficits, including unstable electricity, scarce potable water, and failing septic systems. Its land use is diverse, combining residential zones with small industries, warehouses, informal markets, and light manufacturing activities. Rapid urban growth has worsened issues such as poor drainage, inadequate waste management, seasonal flooding, and occasional oil spills from nearby tank farms, all of which heighten environmental pressure and increase the likelihood of water contamination. Most residents depend on groundwater from hand-dug wells and boreholes for drinking and domestic needs, making water quality a major concern. The area's alluvial soils and proximity to the Lagos Lagoon influence groundwater flow and pollutant mobility. Industrial discharges, waste mismanagement, and vehicular emissions pose additional health risks. This study investigates potentially toxic metals, evaluates groundwater quality, and identifies contamination sources in Ijora-Badia.

MATERIALS AND METHODS

Study Area / Sampling Location

This study was conducted at Ijora - Badia (N6°27'58.6692", E3°21'25.62012"- N6°28'16.66812", E3°21'40.3632"-) area of Lagos - State, Southwestern - Nigeria namely; Gaskiya college road (GCR), Amusu street Adefila (ASA), Fadaini street badia (FSB), Idowu street, ijora badia (ISIB), Matiminu street (MS), 14, Bale street (14BS), 5, Bale street (5BS), Church street (CS), Guva street (GS), Sunday street (SS). (Figure 1).

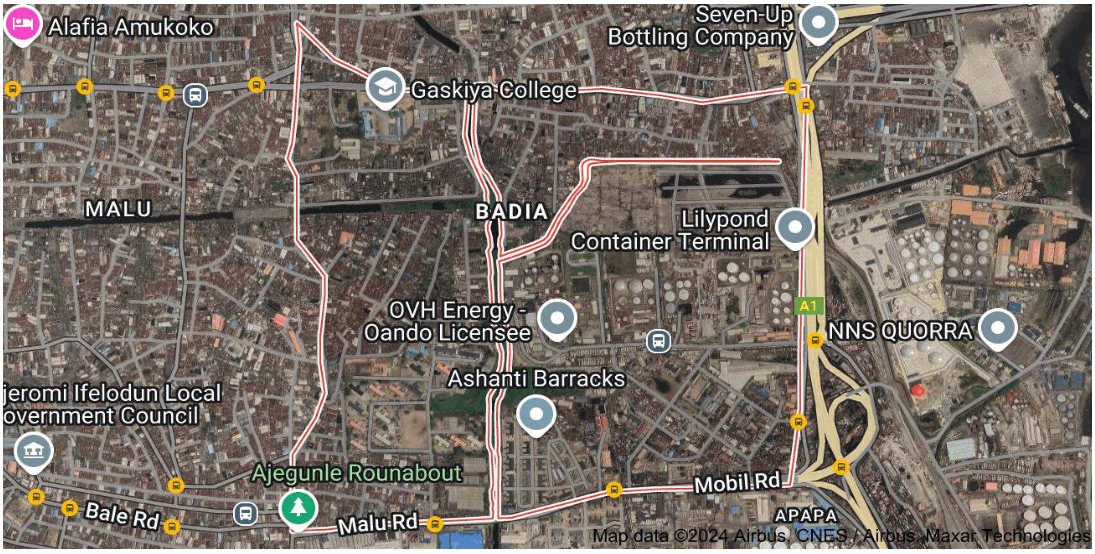

Figure 1: Map of Ijora - Badia

Selection of Sampling Sites/ Locations

Ten (10) Sampling sites were carefully chosen based on Accessibility to groundwater (Well water), natural and anthropogenic activities that may impact on the water quality in the Study area. A Global Positioning System (GPS) device was used to record the coordinates for each sampling site. (GPS 76S Garmin) (Table 1).

Table 1: Sampling Sites, Characteristics and Coordinates of the Study Area

S/N	Location	Sample Code	Coordinates	
			Latitude	Longitude
1	Gaskiya college road	GCR	N6°27'58.6692"	E3°21'40.3632"
2	Amusu street Adefila	ASA	N6°28'3.1368"	E3°21'35.7588"
3	Fadaini street badia	FSB	N6°28'7.8024"	E3°21'33.4152"
4	Idowu street, ijora badia	ISIB	N6°28'6.7368"	E3°21'36.6696"
5	Matiminu street	MS	N6°28'0.9912"	E3°21'39.2508"
6	14, Bale street	14BS	N6°28'9.93958"	E3°21'36.612"
7	5, Bale street	5BS	N6°28'12.9"	E3°21'35.63388"
8	Church street	CS	N6°28'16.66812"	E3°21'34.24212"
9	Guva street	GS	N6°28'12.13212"	E3°21'33.138"
10	Sunday street	SS	N6°28'15.91212"	E3°21'25.62012"

Sampling and Sample Collection

Ten wellwater samples were collected from the Ijora - Badia area of Lagos State, Southwestern Nigeria, for six months (August 2024 - January 2025), four samples per month. Sampling was done using pre-washed plastic bottles, rinsed with distilled water and air-dried. Each container was rinsed three times with the water sample before collection, tightly sealed, and labeled with identification codes. Samples were transported in an ice chest to the laboratory for analysis. The study measured PTMs - Lead (Pb), Cadmium (Cd), Mercury (Hg), Arsenic (As), and Chromium (Cr).

Laboratory Analysis

All chemicals and reagents (Tetraoxosulphate(vi) acid (H_2SO_4), Trioxonitrate (v) acid (HNO_3), Hydrochloric acid (HCl), Mercuric sulphate (HgSO4), Potassium dichromate ($K_2Cr_2O_7$), Distilled water, Ferroin indicator, Ferrous ammonium sulphate (0.25 M FAS), Ethanol, Hydrogen peroxide) used for the laboratory analysis were of analytical grade and purchased from Lazco Scientific in Lagos - State. Nigeria. Laboratory analysis were conducted at the Analytical Chemistry Laboratory of the College Central Research Laboratory, Yaba College of Technology, Yaba - Lagos, Nigeria.

Digestion of Water Samples for PTMs Analysis

Wellwater samples were digested prior to heavy metal analysis using Inductively Coupled Plasma Optical Emission Spectroscopy (ICP - OES). Each sample was thoroughly mixed, and 100 mL was transferred into a 250 mL Pyrex beaker. Ten milliliters of concentrated nitric acid (HNO_3) were added, and the mixture was gently heated on a hot plate and evaporated to approximately 20 mL. An additional 5 mL of HNO_3 and 5 mL of hydrogen peroxide (H_2O_2) were then added, and the beaker was immediately covered with a watch glass. Heating continued until white fumes evolved and a clear solution was obtained. After cooling to room temperature, the digested solution was diluted with distilled water and filtered through Whatman filter paper. The filtrate was transferred into a 100 mL volumetric flask and made up to the mark with distilled water, mixed thoroughly, and stored in polypropylene bottles for ICP - OES analysis.

All samples were processed alongside reagent blanks to ensure data reliability. PTMs- Pb, Cd, Cr, As, and Hg - were quantified using an Agilent 7700 ICP - OES. Analytical quality was maintained by analyzing standard metal mixtures and assessing precision and accuracy through triplicate measurements. Each sample was analyzed in triplicate, and mean concentrations were recorded, following established procedures (APHA, 2017; AOAC, 2000; Ajiwe and Eboagu, 2021; Awang *et al.,* 2025).

Statistical Analysis

Mean values, standard deviations, ANOVA, and Pearson's correlation analyses were conducted. Significant differences of PTMs were assessed using Duncan's Multiple Range Test (DMRT) in SPSS (IBM v27). Superscripts (a - f) in Table 2 indicate group differences. DMRT showed highly significant variations ($p < 0.001$) in all PTMs across sites, with ISIB and FSB having the highest Pb, Cr, and Hg, while GSR showed high As (Table 3). Lead dominated the total PTMs load (92.5%)(Table 2).

Table 2: Mean ± Standard Deviation of Concentrations of PTMs (mg/L)

Locations	As	Cd	Cr	Hg	Pb	%
GSR	0.081 ± 0.0003^a	0.012 ± 0.0026^c	0.142 ± 0.0003^c	0.007 ± 0.0003^c	0.927 ± 0.0003^c	5.7
ASA	0.054 ± 0.0004^d	0.005 ± 0.0003^e	0.042 ± 0.0002^e	0.011 ± 0.0002^b	0.164 ± 0.0003^g	1.3
FSB	0.076 ± 0.0002^b	0.019 ± 0.0004^a	0.388 ± 0.0003^b	0.014 ± 0.0004^a	7.183 ± 0.0002^b	37.3
ISIB	0.061 ± 0.0004^c	0.017 ± 0.0004^b	0.418 ± 0.0036^a	0.014 ± 0.0004^a	8.897 ± 0.0216^a	45.6
MS	0.039 ± 0.0004^e	0.007 ± 0.0004^d	0.060 ± 0.0003^d	0.001 ± 0.0003^e	0.739 ± 0.0003^d	4.1
14BS	0.003 ± 0.0003^j	0.002 ± 0.0003^f	0.011 ± 0.0004^f	-	0.345 ± 0.0003^f	1.8
5BS	0.011 ± 0.0003^g	0.002 ± 0.0004^f	0.010 ± 0.0003^f	-	0.629 ± 0.0003^e	3.2
CS	0.017 ± 0.0004^f	0.002 ± 0.0004^f	-	0.005 ± 0.0003^d	0.024 ± 0.0003^i	0.2
GS	0.006 ± 0.0004^i	0.002 ± 0.0002^f	0.003 ± 0.0003^g	-	0.072 ± 0.0003^h	0.4
SS	0.011 ± 0.0009^h	0.001 ± 0.0004^f	0.003 ± 0.0003^g	-	0.070 ± 0.0316^h	0.4
F-Statistics (p)	30389.977 (<0.001)	332.474 (<0.001)	108107.455 (<0.001)	1518.964 (<0.001)	438062.268 (<0.001)	
%	1.7	0.3	5.2	0.2	92.5	100.0

Table 3: Statistical Analysis of PTMs

PTMs	Range of means (mg/L)	Highest concentration group (letter "a")	Lowest concentration group	Interpretation
As (Arsenic)	0.003 – 0.081	GSR (0.081 ± 0.0003^a)	14BS (0.003 ± 0.0003^j)	GSR has significantly higher As than all other locations; contamination decreases progressively through ASA, ISIB, etc.
Cd(Cadmium)	0.001 – 0.019	FSB (0.019 ± 0.0004^a)	SS (0.001 ± 0.0004^f)	FSB has the highest Cd, significantly greater than all others; lowest Cd in SS, GS, and CS.
Cr(Chromium)	0.003 – 0.418	ISIB (0.418 ± 0.0036^a)	GS/SS (0.003 ± 0.0003^g)	ISIB is significantly more contaminated with Cr; GS and SS have minimal levels.
Hg (Mercury)	0.001 – 0.014	FSB, ISIB (0.014 ± 0.0004^a)	MS (0.001 ± 0.0003^e)	FSB and ISIB have the highest Hg, significantly higher than others; MS has the lowest.
Pb (Lead)	0.024 – 8.897	ISIB (8.897 ± 0.0216^a)	CS (0.024 ± 0.0003^i)	ISIB shows extremely elevated Pb, far exceeding other sites; lowest Pb in CS.

RESULTS AND DISCUSSION

Potential Toxic Metals (PTMs) in Wellwater Samples

Table 4 shows concentrations of PTMs across ten sampling locations. It presents PTMs concentrations, site - specific averages, and percentage contributions of each PTMs to the total contamination load while Figure 2 shows selected photos of wells in the study areas.

Figure 2: Photos of wells in the study area: a - Sunday Street; b - Amusu Street, Adefila; c- Gaskiya, College Road; d- Fadaini Street, Badia; e - Guva Street

Cadmium concentrations in the sampled well water ranged from 0.0014 - 0.0192 mg/L, averaging 0.0069 mg/L(Table 4). The highest values occurred at FSB and ISIB, while the lowest was observed at SS, showing significant variation among sites. All samples exceeded WHO (2015) and NIS (2007) permissible limits (Table 4). Cd levels may results from corrosion of galvanized pipes or leaching from contaminated soils affected by industrial activities such as mining, electroplating, petrochemical processing, and fertilizer production. Prolong Cadmium exposure can cause kidney damage, hypertension, lung cancer, and bone disorders. Effective reduction methods include ion exchange, reverse osmosis, and electrodialysis.

Lead was the most abundant PTM, reflecting significant environmental contamination. High Pb levels may be linked to anthropogenic sources, including heavy vehicular traffic, industrial activities, and automobile emissions. At ISIB, additional contributions arise from the use of leaded petrol in vehicles, generators, and water pumps, which leach into groundwater (Figure 3). Lead concentrations across the ten sampling sites ranged from 0.0244 - 8.8966 mg/L, averaging 1.9048 mg/L (Table 4). FSB and ISIB recorded the highest levels, while CS, GS, and SS were lowest. All values exceeded WHO (2015) and NIS(2007) limits, posing serious health risks and necessitating urgent remediation and stricter environmental controls.

Arsenic is a toxic trace element, and its accumulation in groundwater poses serious ecological and human health risks, particularly in areas impacted by industrial and agricultural activities. In the study area, As concentrations ranged from 0.0035 - 0.0809 mg/L, averaging 0.0359 mg/L, with the highest at GCR and the lowest at 14BS (Table 4). All levels exceeded WHO (2015) and NIS (2007) limits of 0.01 mg/L, indicating significant contamination. Arsenic entered the groundwater through natural geological sources and anthropogenic activities, including smelting, pesticide application, microplastics and chemical production (Foti *et al.,* 2017; Men *et al.,* 2020; Changfeng *et al.,* 2019; Heidari *et al.,* 2021; Ika *et al.,* 2024). Chronic exposure can cause cancer, cardiovascular disease, and neurological damage, highlighting the urgent need for water treatment, monitoring, and regulatory interventions.

Chromium concentrations in well water across the ten sampling sites ranged from 0.0025 - 0.4175 mg/L, averaging 0.1075 mg/L. The highest levels were found at ISIB and FSB, while the lowest occurred at 14BS and 5BS, with SS recording the minimum value of 0.0025 mg/L (Table 4). These concentrations far exceeded the WHO (2015) and NIS (2007) limit of 0.05 mg/L, indicating widespread chromium pollution (Zhang *et al.,* 2023) . CS, however, showed no detectable Cr, suggesting minimal risk at that location. Chromium contamination results from both natural processes, such as rock weathering, and human activities, including chrome plating, steel manufacturing, corrosion control, wood preservation, and paint production (Zhitkovich, 2016).

Mercury was the least abundant PTM in the study area, with concentrations ranging from 0.0008 - 0.0139 mg/L and an average of 0.0051 mg/L (Table 4). The highest levels occurred at ISIB and FSB, while MS recorded the lowest, and several sites, including 14BS, 5BS, and SS, showed no detectable mercury, indicating minimal contamination (Figure 3).. All detected values exceeded WHO (2015) and NIS (2007) limits of 0.001 mg/L, confirming significant pollution. Mercury enters groundwater through natural geology and human activities, such as industrial operations, improper waste disposal, and mercury-containing medical devices. Its persistence and bioaccumulation pose neurological, cognitive, and kidney risks, necessitating strict pollution control, safer waste management, and continuous monitoring.

Table 4: Average Concentrations of PTMs (mg/L)

S/N	Sample Code	As	Cd	Cr	Hg	Pb
1	GCR	0.0809	0.0118	0.1418	0.0073	0.9269
2	ASA	0.0543	0.005	0.0422	0.0106	0.1637
3	FSB	0.0759	0.0192	0.3881	0.0137	7.1829
4	ISIB	0.0608	0.0168	0.4175	0.0139	8.8966
5	MS	0.0393	0.0072	0.0598	0.0008	0.7387
6	14BS	0.0035	0.0019	0.0108	ND	0.3445
7	5BS	0.0111	0.0018	0.0098	ND	0.6287
8	CS	0.0168	0.0023	ND	0.005	0.0244
9	GS	0.0063	0.0018	0.0028	ND	0.0718
10	SS	0.0106	0.0014	0.0025	ND	0.07
Total		0.3595	0.0692	1.0753	0.0513	19.0482
Average		0.0359	0.0069	0.1075	0.0051	1.9048
Percentage (%)		1.745	0.336	5.219	0.249	92.451
W.H.O (2015) ≤		0.01	0.003	0.05	0.001	0.01
NIS (2007) ≤		0.01	0.003	0.05	0.001	0.01

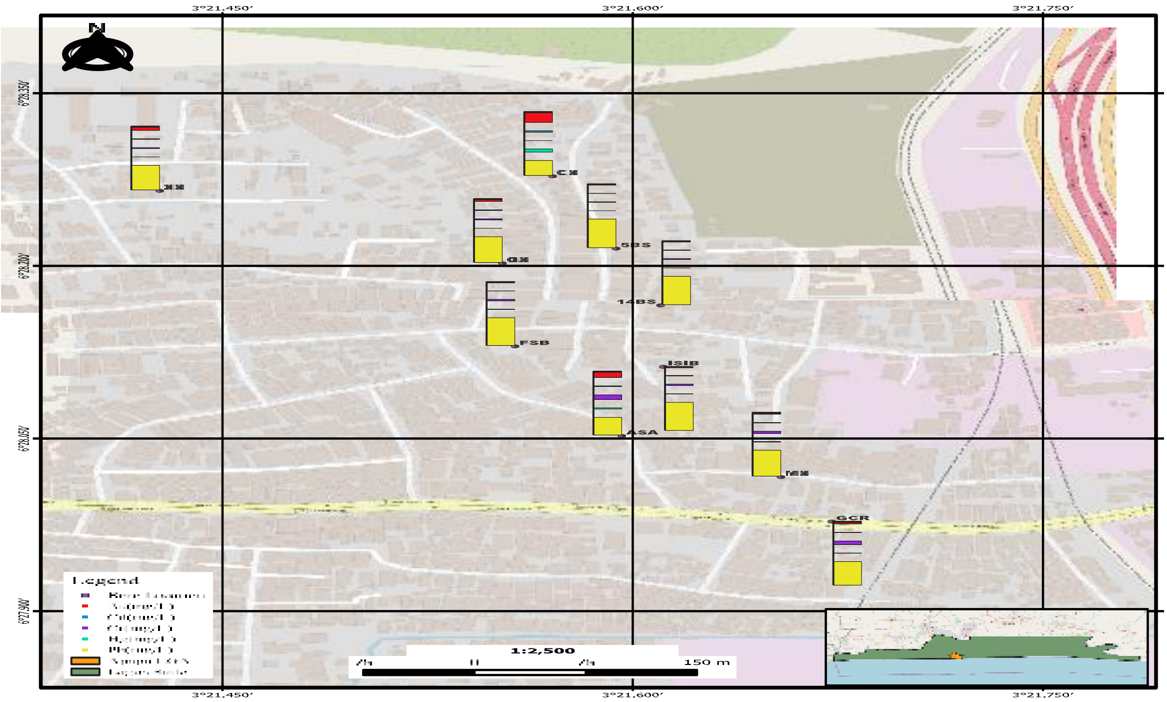

Figure 3: GIS Map Showing the Concentrations of PTMs in the study sites

Idowu Street (ISIB) showed the highest PTM contamination (Figure 4), due to open waste dumping, emissions from nearby industries, automobile repair activities, and poor sanitation. Its closeness to a major dumpsite and industrial discharge zones promotes metal leaching into groundwater, while runoff from busy roads further elevates pollution levels (Yusuf *et al.,* 2018; Ajiwe and Eboagu, 2021; Hassan, 2016) (Figure 4). Church Street (CS) - 0.0244, was the least contaminated, supported by effective urban planning, regulated waste management, green areas, and limited industrial operations (Caerio *et al.,* 2005; Yusuf *et al.,* 2018). PTM levels increased from August 2024 to January 2025, reflecting seasonal bioaccumulation during the dry season. The distribution follows the pattern : Pb > Cr > As > Cd > Hg (Figure 5).

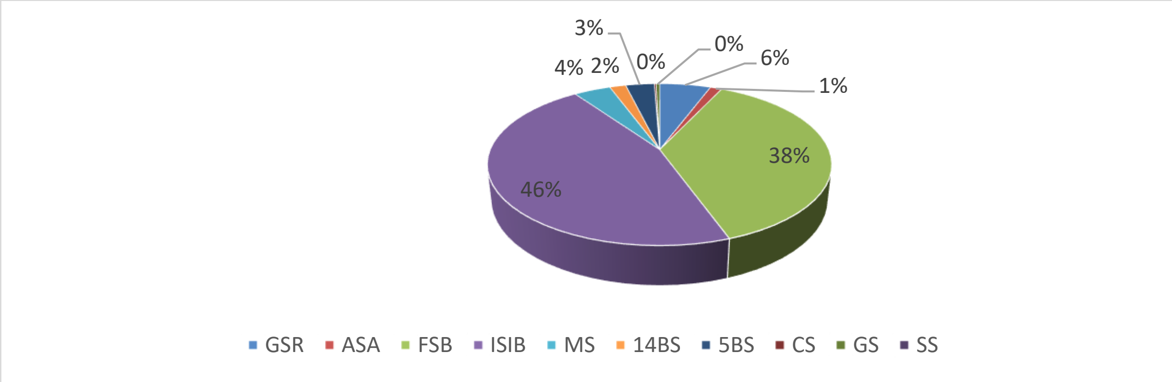

Figure 4: Percentage contribution of PTMs to Pollution in each site

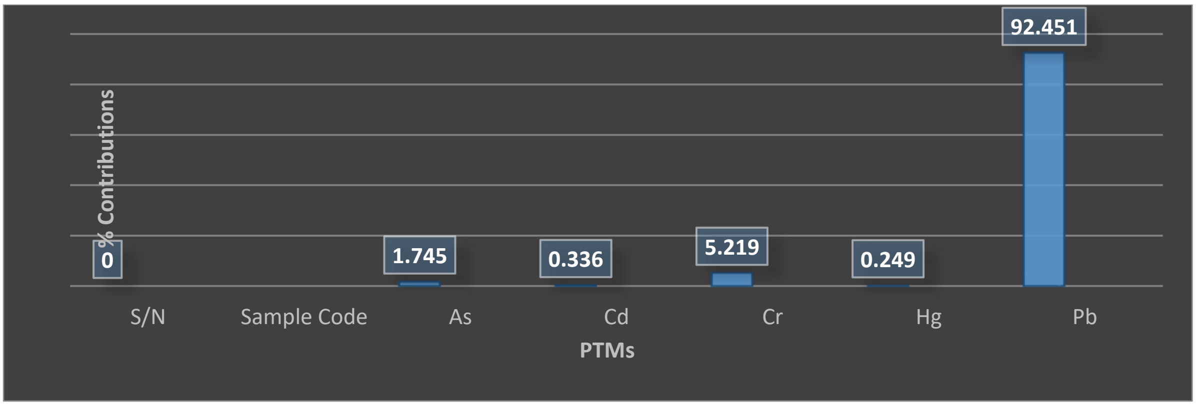

Figure 5: Percentage contribution of PTMs in Ijora - Badia Area

Water Quality Indices

Water Quality Indices (WQI) serves as tools for assessing water quality based on the concentration of all present metals (Adano *et al.,* 2023). Heavy Metal Pollution Index (HPI), Pollution Index (PI), and Metal Index (MI) were used to assess the pollution levels of Ijora - Badia wellwater.

The Heavy Metal Pollution Index (HPI) is a ranking method assessing the cumulative impact of various heavy metals on water quality by comparing measured values with defined critical limits (Yusuf *et al.,* 2018). In this study, HPI values ranged from 112.01 (CS) to 12,776.91 (ISIB), with ISIB (12,776.91) and FSB (10,452.38) far exceeding the threshold of 100 (Table 5). These high values indicate severe contamination, posing risks of kidney damage, neurological disorders, and cancer (Ajiwe and Eboagu, 2021). The mean HPI of 1629.83 confirms widespread pollution (Table 6), with lead as the major contributor, while mercury and arsenic also significantly impact water quality. Urgent remediation and stricter environmental controls are needed to protect public health.

The Metal Index (MI) was used to evaluate pollution levels and potential health risks from consuming contaminated water. MI values revealed alarming pollution, with the highest at ISIB (912.01) and FSB (742.33), indicating severe contamination (Table 5). Values above 1 are considered unsafe for drinking (Perpetual *et al.,* 2022), while MI >3 signals hazardous water quality (Caeiro *et al.,* 2005). CS -(5.72), GS -(8.47), and SS -(8.58) showed moderate contamination. The overall MI for Ijora - Badia well water was 203.62, far exceeding the critical limit of 6.0 (Table 6), confirming severe PTM contamination. According to classification criteria **(**Caerio *et al.,* 2005) (Table 7), the water is unsuitable for both consumption and domestic use.

Table 5: Heavy Metal Pollution Index (HPI) and Metal Index (MI) in Each Site in the Study Area

S/N	Sample Code	As	Cd	Cr	Hg	Pb	HPI	MI
1	GCR	0.0809	0.0118	0.1418	0.0073	0.9269	1617.86	108.77
2	ASA	0.0543	0.005	0.0422	0.0106	0.1637	423.18	26.08
3	FSB	0.0759	0.0192	0.3881	0.0137	7.1829	10452.38	742.33
4	ISIB	0.0608	0.0168	0.4175	0.0139	8.8966	12776.91	912.01
5	MS	0.0393	0.0072	0.0598	0.0008	0.7387	1198.08	81.53
6	14BS	0.0035	0.0019	0.0108	ND	0.3445	513.25	35.65
7	5BS	0.0111	0.0018	0.0098	ND	0.6287	916.93	64.78
8	CS	0.0168	0.0023	ND	0.005	0.0244	112.01	5.72
9	GS	0.0063	0.0018	0.0028	ND	0.0718	136.41	8.47
10	SS	0.0106	0.0014	0.0025	ND	0.07	133.69	8.58

Table 6: Mean Heavy Metal Pollution (HPI) and Metal Index (MI) in the Study Area

PTMs	Mean Conc. (MC) (mg/L)	Highest Permissible value (S_i) (NIS, 2007)	Unit weightage $Wi = \frac{1}{(Si)}$	Sub index $Qi = 100 \times \frac{MC}{(Si)}$	$W_i \times Q_i$	Mean Value		
						$MI = \frac{MC}{Si}$	HPI	MI
Arsenic (As)	0.0359	0.01	100	359	35900	3.59	1629.83	203.62
Cadmium (Cd)	0.0069	0.003	333.333	230	76666.59	2.3		
Chromium (Cr)	0.1075	0.05	20	215	4300	2.15		
Mercury (Hg)	0.0051	0.001	1000	510	510000	5.1		
Lead (pb)	1.9048	0.01	100	19048	1904800	5.1		
	2.0602		1,553.333		2,531,666.6	$\sum MI = 203.62$		

Source: Yusuf *et al.,* 2018.

$$HPI = \frac{\sum W_i Q_i}{\sum W_i} = \frac{2531666.6}{1553.333} = 1{,}629.83$$

Table 7: Water quality Classification using MI

MI	Characteristics	Class
< 0.3	Very pure	1
0.3 – 1.0	Pure	11
1.0 – 2.0	Slightly affected	111
2.0 – 4.0	Moderately affected	1V
4.0 – 6.0	Strongly affected	V
>6.0	Seriously affected	VI

Source: Caerio *et al.,* 2005

The Pollution Index (PI) represents the ratio of each parameter's concentration to WHO standards, indicating relative pollution levels. A PI above 1.0 signifies significant contamination, while values below 1.0 indicate no pollution. In this study, PTMs showed high PI values: As (3.59), Cd (2.3), Cr (2.15), Hg (5.1), and Pb (190.48), with lead posing the greatest health risk (Table 8). PI for Pb and Cd exceeded 3 at ISIB, and the mean PI for Ijora - Badia well water was 203.62, highlighting the urgent need for effective waste management, water treatment, and continuous monitoring.

Table 8: Pollution Index (PI) of Well Water Samples

PTMs	Mean Concentration (MC)	WHO Limit (S) (2017)	$PI = \frac{CONCENTRATION}{STANDARD}$
Arsenic (As)	0.0359	0.01	3.59
Cadmium (Cd)	0.0069	0.003	2.3
Chromium (Cr)	0.1075	0.05	2.15
Mercury (Hg)	0.0051	0.001	5.1
Lead (pb)	1.9048	0.01	190.48
			$\sum PI = 203.62$

Source: Ajiwe and Eboagu, 2021

Source Apportionment

Using Principal Component Analysis (PCA) to Identify the Potential Sources of PTMs

Principal Component Analysis (PCA) is a multivariate technique that employs eigenvalues to structure datasets and identify pollution sources based on measured variables (Table 10). It simplifies large datasets into fewer components, aiding in tracing PTM sources in Ijora - Badia groundwater. In this study, concentrations of As, Cd, Cr, Hg, and Pb formed the data matrix, with sampling sites as rows. A variance-normalized matrix was examined using Varimax rotation with Kaiser normalization. The KMO value (0.695) confirmed sampling adequacy, while Bartlett's test ($\chi^2(10) = 641.727$, $p < .05$) showed significant correlations (Table 9). Based on scree plot and eigenvalue criteria, one component -PC1 - was identified which accounted for 86.45% of the variance and indicating contributions from traffic emissions, industrial waste, fossil-fuel combustion, geogenic inputs, mining, smelting, microplastics, and oil spills(Foti *et al.,* 2017; Men *et al.,* 2020; Changfeng *et al.,* 2019; Heidari *et al.,* 2021; Ika *et al.,* 2024).

Table 9: KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.695
Bartlett's Test of Sphericity	Approx. Chi-Square	641.727
	Df	10
	Sig.	<.001

Table 10: The Rotated Component Matrix for Data of PTMs

PTMs	Factor
	PC1
As	.813
Cd	.989
Cr	.982
Hg	.889
Pb	.881
Eigenvalues	4.323
% of Total Variance	86.451
Extraction Method: Principal component.	

Correlation Analysis

Pearson's correlation analysis was used to examine statistical relationships between potentially toxic metals (PTMs) and their possible sources in well water. The Pearson correlation coefficient (r) measures the strength and direction of associations among metals. As shown in Table 11, strong and significant positive correlations were observed among all PTMs in Ijora - Badia groundwater, indicating that fewer components are needed to explain dataset variability. Correlation values for As, Cd, Cr, Hg, and Pb (0.743 - 0.976) confirm the dataset's suitability for PCA. These strong correlations suggest common anthropogenic sources such as vehicular emissions, industrial and municipal waste, sewage sludge, fossil-fuel combustion, geogenic inputs, mining, smelting, and oil spills.

Table 11: Correlation Coefficient Analysis among the PTMs (N = 66)

Metals	As	Cd	Cr	Hg	Pb
As	1				
Cd	**.870**	1			
Cr	**.743**	**.953**	1		
Hg	**.834**	**.837**	**.835**	1	
Pb	**.591**	**.876**	**.976**	**.771**	1
Mean	.036	.007	.107	.005	1.905
SD	.029	.006	.155	.005	3.131

CONCLUSION

This study provides strong evidence of severe groundwater contamination in the Ijora - Badia area, with PTM concentrations far exceeding national and international safety standards. Lead was the dominant pollutant, followed by chromium, arsenic, cadmium, and mercury, reflecting contamination largely linked to industrial activities, vehicle emissions, poor waste disposal, and possible geological inputs. PCA results identified one major factor accounting for most of the variance, indicating that the pollution comes from common sources. Pollution indices such as HPI, MI, and PI consistently indicated high contamination, while correlation analyses confirmed widespread pollution. These findings show that Ijora - Badia well water is unsafe for domestic use without advanced treatment.

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