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Research Article

Determination of heavy metal contamination in well water from selected locations within Kaduna metropolis

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ABSTRACT

This study aimed to measure heavy metal (Pb, Cr, Cd, Co, Hg, Ni, Fe, Mn, Zn and Cu) levels in well water from five locations in Kaduna: Unguwan Sarki, Kawo, Barakallahu, Mando, and Mahuta Estate. It also compared these levels with WHO standards and evaluated potential health risks to residents. The hand-dug well water samples were collected, acidified to a pH below 2 for preservation, and analysed using atomic absorption spectrophotometry (AAS). Results showed that 70% of the heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni), copper (Cu), manganese (Mn), and zinc (Zn)—were within WHO safety limits. However, notably high iron (Fe) levels were found in Unguwan Sarki (0.412 mg/L) and Mahuta Estate (0.728 mg/L), both surpassing the WHO limit of 0.3 mg/L. In conclusion, while most metals are within safe levels, the elevated iron levels at two locations indicate a need for targeted measures to protect public health, as it causes significant aesthetic issues such as altering the water taste and can also cause staining. The Hazard index for Ungwan Sarki, Barkallahu, and Kawo is on the high side, indicating that these locations are prone to hazards from these heavy metals. The CDI showed Barakallahu leading in the intake of Cr, Ni, Mn, and Copper; Kawo and Mando showed more consistent levels of the toxic heavy metals, while Ungwan Sarki showed the highest Cd intake overall. Variations across sites suggest local geology or pollution sources affect water quality. Recommendations involve further investigation into iron sources, health awareness campaigns, water treatment options, and regulatory enforcement to maintain water safety.

Keywords: Heavy metals, Well water, Concentration, A.A.S and WHO

Introduction

Water is a vital natural resource essential for the survival and thriving of all living beings, from tiny microorganisms to complex animals. Our main sources include surface water, such as lakes, rivers, and streams, and underground reservoirs, such as boreholes and wells. Due to its molecular traits, especially its polarity and hydrogen-bonding capacity, water can dissolve, absorb, or suspend many substances. As a result, in its natural state, water is rarely pure; it readily absorbs contaminants from its surroundings and from human, animal, and other biological activities (1).

Groundwater contamination is a critical global environmental concern. Among pollutants affecting water resources, heavy metals stand out for their high toxicity even at very low levels (2). These metals are generally defined as metallic elements with a density of over 5 g/cm^3. In aquatic settings, they can occur in various forms, including suspended particles, colloids, and dissolved substances. While some presence results from natural geological processes like soil erosion and mineral breakdown, a growing portion stems from human activities. These include industrial wastewater discharge, urban runoff, raw sewage, municipal waste, mining, and the extensive use of agrochemicals (3). Additionally, improper waste disposal, particularly of electronic waste and landfill leachate, greatly worsens this issue (4).

Certain heavy metals, such as copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn), are essential trace elements required in small quantities for healthy bodily functions (Olalekan et al., 2018). However, excessive exposure to any heavy metal can cause serious health problems. These metals can disrupt biological systems by generating reactive oxygen species (ROS), which lead to oxidative damage, and can also interfere with metabolic processes and enzyme activity (5). People are often exposed to various heavy metals, including Lead (Pb), Cadmium (Cd), Mercury (Hg), Nickel (Ni), Chromium (Cr), Copper (Cu), Iron (Fe), Manganese (Mn), Zinc (Zn), and Cobalt (Co) (Emmanuel et al., 2022). These metals are linked to numerous severe health issues. For example, Cadmium (Cd) is a known carcinogen (4). Consuming hexavalent chromium (Cr (VI)) in drinking water can lead to cancer. Lead (Pb) can cause long-term health concerns such as headaches, loss of appetite, birth defects, intellectual disabilities, hypertension, lung cancer, and kidney damage (6). Mercury (Hg) exposure can be fatal and has been associated with neurological problems and joint issues (6). Nickel (Ni) exposure has been linked to cardiovascular and kidney diseases, as well as nasal cancers(2). Elevated Copper (Cu) levels may cause gastrointestinal problems and liver damage, while excessive Zn if ingested above the Oral Reference Dose of 0.3 mg/kg/day, can lead to cell death in the brain (2). Additionally, heavy metals such as Pb and Cd are associated with kidney failure, and Cu and Co may contribute to liver cirrhosis (4).

In many areas, especially in Nigeria, communities rely more on groundwater sources like shallow wells and boreholes to meet their daily water needs, mainly due to inadequate public water infrastructure (4). A research carried out in a part of Mando in Kaduna state showed that the results for heavy metals Pb (0.0001-0.0021), Cu (0.2344-0.6727), Zn (0.0594-2.3156), Mg (0.2712-6.1246), Co (0.1460-0.9186), Ni (0.6725-0.9826) and Hg (0.0008-0.2002) in varied concentration compared with the Nigerian standard of drinking water showed that Ni, Co and Mg had higher concentration than the acceptable values and thus the people in that area are vulnerable to have health challenges of cancer, mental development in infants, hearing and visual impairment [9]. The quality of this groundwater is heavily influenced by the geological features of the soil and rock layers it passes through, as well as by widespread human activities (4). Sources of contamination include industrial discharges, vehicle emissions, municipal waste, hazardous waste sites, and agricultural practices, all of which contribute to a growing problem of heavy metal contamination in groundwater (3).

This growing issue underscores the urgent need for thorough, regular assessment of groundwater quality to safeguard public health. Heavy metals can enter groundwater both naturally and through human activities. Natural processes such as mineral erosion, rock weathering, and leaching from ore deposits establish baseline levels, but human activities often lead to higher concentrations in contaminated zones (3,4,2). Mechanical workshops and busy areas contribute Lead (Pb) and Cadmium (Cd) to groundwater via runoff and soil leaching (7).

As most studies carried out in Kaduna were done in the southern part of Kaduna, with only a few carried out on the northern side which did not cover vast areas, this study tends to look more into the northern side, as all the different sample location sites are in the northern axis of Kaduna State and cover more heavy metals than the initial ones done.

Key anthropogenic sources include:

Industrial Discharges: Wastewater from various industries frequently has high levels of heavy metals. When these untreated or inadequately treated effluents are discharged into surface water bodies or directly onto land, they can seep into the ground and contaminate aquifers (3,4,2).

Agricultural Activities: The application of agrochemicals such as fertilizers and pesticides can lead to the introduction of heavy metals into the soil. Runoff from agricultural fields and leaching processes can then carry these metals into groundwater (3,2)

Waste Disposal Sites (Landfills): Poorly managed solid waste disposal sites, especially those using inadequate techniques, generate leachate—contaminated liquid that forms when rainwater passes through waste. This leachate is high in heavy metals and can infiltrate the soil, thereby polluting groundwater(4,2). E-waste dumping also adds to this issue (4).

Urban Runoff and Domestic Effluents: Stormwater runoff from urban areas can transport heavy metals from vehicular emissions and other urban activities. Domestic sewage also contributes to metal loads in groundwater (2).

Mining Operations: Mining activities can greatly contribute to heavy metal contamination, especially in regions with coal deposits (5)

Health Effects of Heavy Metal Contamination

Extended exposure to heavy metals, even in small amounts, can cause various immediate and long-term health issues, depending on the metal type, exposure level, duration, and individual factors (4,5,2). The heavy metals commonly encountered and their health effects, as described in the research, include: i. Lead (Pb): An extremely toxic element responsible for chronic health problems like headaches, appetite loss, birth defects, intellectual disabilities, hypertension, lung cancer, and kidney damage. It accumulates in the body and affects the central nervous system (6,4,5). ii. Cadmium (Cd): A carcinogen linked to kidney failure and higher cancer risk in children, often found above safety limits (6,4,2). iii. Mercury (Hg): A dangerous metal that can cause neurological and joint issues (6,5). iv. Nickel (Ni): Exposure may cause heart, kidney, lung, and nasal cancers (2). v. Chromium (Cr): Especially hexavalent chromium (Cr (VI)), a known carcinogen that, when present in drinking water, may lead to cancer (2). vi. Copper (Cu): Necessary in small amounts, but excess can lead to gastrointestinal and liver problems (2). vii. Iron (Fe): Excess levels can cause water cloudiness and are associated with pollution (4,5). viii. Manganese (Mn): Often found in wells and boreholes at high concentrations (5). ix. Zinc (Zn): Essential as a micronutrient, but too much can trigger cell death in the brain

(2). x. Cobalt (Co): Along with copper, can contribute to liver cirrhosis (4).

Material and Methods

Reagents

Distilled water**,** Nitric acid (conc.) (HNO_3), Hydrochloric acid (conc.) (HCl)

Study Area

The study was conducted in Kaduna State, with samples which are gotten from hand-dug wells of 5-20 metres in depth and have been there in existence for over 35 years, collected from five locations: Unguwan Sarki (latitude:10.5416^0 N and longitude: 7.4449^0 E), Kawo (latitude:10.5777^0 N and longitude: 7.4485^0 E), Mando (latitude:10.5960^0 N and longitude: 7.4080^0 E), Barakallahu (latitude:10.6300^0 N and longitude: 7.4600^0 E), and Mahuta Estate (latitude:11.2920^0 N and longitude: 7.7934^0 E).

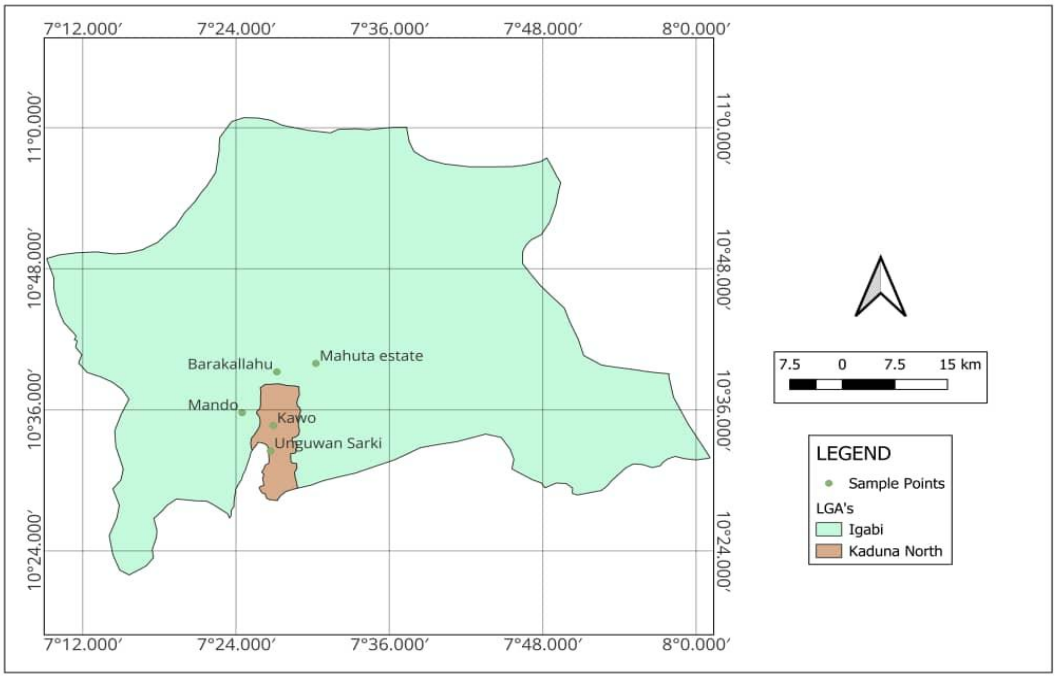


Figure 1. Map of Study Area

Sampling Procedures

Sampling Design, Collection and Storage

The five (5) water samples were collected through grab sampling from sites across the study area, including common groundwater sources such as hand-dug wells used by locals. A random sampling method was used to obtain a representative overview of the area, accounting for potential land-use differences. Samples were stored in 500 mL plastic bottles, which were carefully cleaned and rinsed with distilled water beforehand to avoid contamination. Samples were collected once the water's physicochemical properties were stable, ensuring they accurately reflected the well water.

Immediately after collection, each water sample was carefully preserved by acidification. This vital step involves gradually adding concentrated nitric acid (HNO_3) until the pH drops below 2. This process is crucial to prevent dissolved metals from precipitating and adhering to the container walls during transport and storage (2).

Sample Digestion and AAS Analysis

A 10 mL sample was weighed into a 50 mL beaker, to which 2.5 mL of Perchloric acid was added as an oxidizing agent. The beaker was placed on a hotplate set to 100-170 °C until the mixture nearly dried and a precipitate formed. The beaker was then removed from the heat, allowed to cool, and three drops of distilled water were added. After mixing, the solution was poured through a funnel with filter paper [8]. The filtrate was measured, adjusted to 50 mL, and then transferred to a sample bottle for AAS analysis.

The water samples were prepared and then analysed using an Atomic Absorption Spectrophotometer to precisely measure specific heavy metals such as Pb, Cd, Cu, Fe, Mn, Hg, Ni, Zn, Cr, and Co.

This AAS instrument, which employs an air-acetylene flame and element-specific hollow cathode lamps as resonance sources, was used following standard procedures. The detection wavelengths for each element were set according to the device's guidelines.

- Lead (Pb): 283.31 nm
- Cadmium (Cd): 228.80 nm
- Copper (Cu): 324.75 nm
- Iron (Fe): 248.33 nm
- Manganese (Mn): 279.48 nm
- Mercury (Hg): 253.7 nm

- Nickel (Ni): 232.00 nm
- Zinc (Zn): 213.86 nm
- Chromium (Cr): 357.87 nm30
- Cobalt (Co): 240.73 nm

For each heavy metal, a specific calibration curve was generated using carefully prepared standard solutions. The Atomic Absorption Spectrophotometer then accurately measured the absorbance of each digested sample, with the metal concentration (mg/L) automatically derived from its respective standard curve. To ensure high accuracy and reliability, all samples, including the deionized distilled water control, were analysed in duplicate, and their average concentration was recorded.

Results and Discussion

Water samples collected from five locations, Unguwan Sarki, Kawo, Barakallahu, Mando, and Mahuta Estate, were analyzed to determine concentrations of heavy metals. These metals included Co, Mn, Hg, Ni, Fe, Cu, Zn, Cd, Cr, and Pb. The findings, presented as mean concentrations with their respective Standard Errors of the Mean (SEM) in milligrams per liter (mgL), are summarized in Tables 1 and 2.

Table 1. Concentration of some heavy metals in the water samples (mg/L) in comparison with WHO standard

Heavy Metal	Unguwan Sarki	Kawo	Barakallahu	Mando	Mahuta Estate	WHO Guideline (mg/L)
Co	0.083±0.001	0.054±0.007	0.044±0.003	0.052±0.001	0.047±0.000	-
Mn	0.001±0.001	0.012±0.001	0.073±0.001	0.006±0.001	0.018±0.001	0.4
Hg	−0.101±0.001	−0.529±0.610	−0.095±0.001	−0.103±0.001	−0.130±0.001	0.006
Ni	0.005±0.001	0.011±0.001	0.022±0.001	0.008±0.001	0.013±0.002	0.07
Cu	0.024±0.001	0.027±0.001	0.029±0.001	0.026±0.001	0.027±0.001	2
Zn	0.086±0.001	0.053±0.001	0.051±0.002	0.085±0.003	0.113±0.003	3
Cd	0.023±0.003	0.022±0.002	0.018±0.002	0.016±0.002	0.015±0.004	0.003
Cr	0.035±0.291	0.004±0.001	0.106±0.001	0.007±0.002	−0.003±0.001	0.05
Pb	0.001±0.001	0.003±0.011	0.005±0.015	0.002±0.001	0.004±0.004	0.01
Fe	0.412±	0.257±	0.175±0.001	0.345±0.001	0.728±0.003	0.3

The result is mean ± SEM, n=3

Note: Negative values for some heavy metals (Hg, Cr) are likely due to improper blank corrections, incorrect calibration curve, or an instrument drift of the analytical instrument and should be treated as non-detectable or zero.

Heavy metal concentrations in the water samples showed considerable variability across the five sampling locations. A significant finding was the wide range of concentrations observed for specific metals. This suggests that the study sites likely have diverse sources of contamination or notable differences in their water chemistry and prevailing environmental conditions.

Anova Report

Based on the paired t-test results, there are no statistically significant differences in the heavy metal concentrations across the 5 locations (Ungwan Sarki, Kawo, Barakallahu, Mando, and Mahuta Estate) at the 95% confidence level.

All pairwise comparisons returned p-values above 0.05, indicating that the heavy metal profiles (Co, Mn, Hg, Ni, Cu, Zn, Cd, Cr, Pb, Fe) are statistically similar across all five sites.

The contamination levels, while present, appear uniformly distributed across the study area with no location standing out as significantly more or less contaminated than the others.

Table 2. Chronic Daily Intake (CDI) mg/kg/day

Location	Cd	Cr	Pb	Ni	Fe	Mn	Cu	Zn
Ungwan Sarki	0.000657	0.001000	0.000029	0.000143	0.011771	0.000029	0.000686	0.002457
Kawo	0.000629	0.001140	0.000086	0.000314	0.007343	0.000343	0.000771	0.001514
Barakallahu	0.000514	0.003029	0.000143	0.000629	0.005000	0.002086	0.000829	0.001457
Mando	0.000475	0.000200	0.000057	0.000229	0.009857	0.000171	0.000743	0.002429
Mahuta estate	0.000429	0.0000*	0.000114	0.000371	0.020800	0.000514	0.000771	0.003229

Table 3. Hazard Quotient (HQ) and Hazard Index (HI)

Location Ungwan sarki	Location Kawo	Location Barakallahu	Location Mando	Location Mahuta Estate
Cd: 1.314	Cd: 1.257	Cd: 1.028	Cd: 0.914	Cd: 0.857
Cr: 0.333	Cr: 0.038	Cr: 1.009	Cr: 0.067	Cr: 0.000
Pb: 0.008	Pb: 0.024	Pb: 0.041	Pb: 0.016	Pb: 0.033
HI: 1.655	HI: 1.319	HI: 2.078	HI: 0.997	HI: 0.890

Of note; none-carcinogenic risk is HI>1

Table 4. Cancer Risk

Location	Cd	Cr	Pb
Ungwan Sarki	9.85×10^{-3}	5.00×10^{-4}	2.47×10^{-7}
Kawo	9.43×10^{-3}	5.71×10^{-5}	7.41×10^{-7}
Barakallahu	7.71×10^{-3}	1.51×10^{-3}	1.23×10^{-6}
Mando	6.86×10^{-3}	1.00×10^{-4}	4.86×10^{-7}
Mahuta Estate	6.43×10^{-3}	0.00	9.71×10^{-7}

Comparison with National and International Standards

When assessing the study's findings, an essential step is to compare the measured heavy metal levels with established drinking water quality standards. The data were compared to the World Health Organization (WHO) guidelines, which are a globally recognized standard for safe drinking water. This comparison helps contextualize the findings and determine the potential health risks posed to the local population.

A comparative analysis of heavy metal concentrations in water samples relative to WHO drinking water guidelines. Iron levels in Unguwan Sarki (0.412 mg/L) and Mahuta Estate (0.728 mg/L) exceeded the WHO limit of 0.3 mg/L. Lead concentrations were below the 0.01 mg/L guideline at all sites, with the highest being 0.005 mg/L in Barakallahu. Cadmium levels remained under the 0.003 mg/L threshold throughout all sampling locations. Chromium was detected only in Barakallahu at 0.02 mg/L, remaining below the WHO limit of 0.05 mg/L. Other Cr and Hg results, which are negative, likely indicate concentrations below detection limits. All other heavy metals analyzed, including Mn, Ni, Cu, and Zn, were found to be within their respective WHO guidelines for drinking water.

All measured concentrations of Pb were below the World Health Organization (WHO) guideline of 0.01 mg/L. The highest level recorded was 0.005 ± 0.015 mg/L in Barakallahu. Fe and Zn: Fe concentrations were highest in Mahuta Estate at 0.728 ± 0.003 mg/L and in Unguwan Sarki at 0.412 ± 0.001 mg/L. Zn concentrations also varied, with Mahuta Estate again recording the highest level at 0.113 ± 0.003 mg/L. While the presence of these metals often stems from natural geological processes, elevated concentrations can also indicate pollution from sources such as industrial discharges, corrosion of galvanized pipes, or mining operations. The significant levels of Fe and Zn in water samples from Mahuta Estate warrant a closer look to pinpoint the specific sources of these metals in that area.

All samples fell within the WHO limit of 0.003 mg/L. The highest detected level was 0.0015 ± 0.002 mg/L, also at Barakallahu. Similarly, nickel levels were low, reaching up to 0.022 ± 0.001 mg/L at Barakallahu. While these levels are not immediately dangerous, the presence of these toxic heavy metals—even at low concentrations—is concerning because they can accumulate over time and cause long-term health problems. This aligns with research by(6), which raises concerns about low-level heavy metal exposure in Nigerian drinking water sources. Cr and Hg: Tests for Cr and Hg sometimes reported negative values, likely indicating levels below the detection limit. However, a positive Cr level of 0.106 ± 0.001 mg/L at Barakallahu suggests potential contamination sources at that site. Notably, even trace amounts of mercury pose significant health risks due to its high toxicity.

Manganese (Mn) reached its peak concentration in Barakallahu at 0.073±0.001 mg/L. Cu levels were relatively consistent across all sites, ranging from 0.024±0.001 mg/L to 0.029±0.001 mg/L. Co was highest in Unguwan Sarki at 0.083±0.001 mg/L. Although these levels are below those of Pb, they still contribute to the total heavy metal load in the water.

Conclusion

This study analyzed heavy metal concentrations in water samples from five locations in Kaduna: Unguwan Sarki, Kawo, Barakallahu, Mando, and Mahuta Estate. Most metals, such as Pb, cadmium (Cd), and chromium (Cr), stayed within WHO safety limits. However, Fe levels in Unguwan Sarki and Mahuta Estate exceeded the WHO-recommended thresholds. The Hazard index values of some locations, Unguwan Sarki, Kawo, and Barakallahu, showed high values greater than 1 and thus are alarming to the health of the people living in those areas. The CDI values are also threatening to the health of the people and therefore measures to curtail it should be taken. Metals like Ni, Cu, Mn, and Zn also remained within safe ranges. Variations in metal amounts across sites indicate effects from local geology and pollution sources. The results emphasize the need for focused measures to reduce iron levels and protect public health from water with taste and stains.

Author Contributions

SS and JYI conceptualized the work, while FMO and AA carried out the methodology and wrote the original draft. All authors then critically reviewed the following versions. All authors have read and approved the final version of the paper and its submission and have given consent for publication.

Declaration of Generative AI and AI-Assisted Technologies in Scientific Writing

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All relevant data are available within the manuscript

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Conflict of Interest

The authors declare that they have no conflicts of interest.

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