

Comparative Assessment of Heavy Metal Contamination in River, Borehole, and Well Water Sources in Kaduna South Metropolis, Nigeria

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Abstract: Water is an essential resource for human survival, agriculture, and industrial development, yet contamination from heavy metals has become a major environmental and public health concern. This study presents a comparative assessment of heavy metal concentrations in river, borehole, and well water sources within Kaduna South Metropolis, Nigeria. Water samples were collected from representative locations and analyzed for zinc (Zn), cadmium (Cd), lead (Pb), chromium (Cr), and iron (Fe) using Atomic Absorption Spectrophotometry (AAS). The results were compared with the drinking water standards of the World Health Organization (WHO). Zinc concentrations (0.089–0.161 mg/L) were within permissible limits, whereas Cd, Pb, Cr, and Fe exceeded WHO guidelines in most samples. Borehole water recorded extremely high Cd concentration (4.138 mg/L), river water showed excessive Fe (13.431 mg/L), and well water exhibited elevated Pb and Fe levels. The contamination is attributed to industrial effluents, agricultural runoff, poor waste management, and geological factors. The study concludes that none of the investigated water sources are safe for direct consumption without treatment and recommends regular monitoring, improved waste management, and enforcement of environmental regulations.

Keywords—Heavy metals, Water quality, Atomic Absorption Spectrophotometry, Kaduna South, Public Health

1. INTRODUCTION

Access to safe and clean drinking water is a human right recognized by international organizations such as the United Nations (UN) and the World Health Organization (WHO). In Nigeria, like many other countries, groundwater from boreholes and well water from streams and rivers are the primary sources of drinking water for both rural and urban communities. However, the quality of water from these sources can vary significantly, and the presence of heavy metals in drinking water is a growing concern (WHO, 2017).

Water is an indispensable resource for human survival, agricultural productivity, and industrial activities. However, rapid urbanization, industrial expansion, and poor waste management have increasingly threatened the quality of water sources in many developing countries, including Nigeria. Heavy metals such as lead (Pb), cadmium (Cd), Zinc (Zn), arsenic (As), and chromium (Cr) are of particular concern because they are toxic even at trace concentrations and can bioaccumulate in the human body over time (Förstner & Wittmann, 2012; World Health Organization [WHO], 2017).

In Kaduna Metropolis, both surface and groundwater sources are susceptible to heavy metal contamination. The metropolis has witnessed significant industrial growth, especially in manufacturing, metal works, and battery recycling, alongside increased agricultural activities. These developments have created multiple pathways for heavy

metals to enter the environment through industrial effluents, agricultural runoff, urban stormwater, and domestic waste discharge (Yusuf et al., 2020).

Heavy metals are naturally occurring elements with high atomic weights, including (but not limited to) Lead (Pb), Copper (Cu), Chromium (Cr), Zinc (Zn), and Cadmium (Cd). These metals are ubiquitous in the environment, and while they are essential in trace amounts for various biological processes, excessive exposure to heavy metals can be toxic to humans and the environment. Sources of heavy metal contamination in water include natural Geological process, industrial activities, agriculture and runoff. Therefore, the study of comparison of heavy metal concentration in river, borehole, and well water within Kaduna South Metropolis, Kaduna State, Nigeria, is of paramount importance.

Kaduna State, located in the northwest part of Nigeria, has been facing water quality challenges for several years (Ukwenya et al., 2023). Despite being endowed with abundant water resources, including numerous rivers and aquifers, ensuring safe and clean drinking water remains a significant challenge. Pollution from various sources, including industrial activities, agricultural runoff, and urbanization, has the potential to contaminate both surface and groundwater sources (Abubakar et al., 2021; Opasola & Otto, 2024).

. This study is highly significant as the findings serve as an important reference for policymakers, environmental protection agencies, and public health authorities in

formulating effective water quality regulations, monitoring frameworks, and pollution control strategies. Additionally, the study raises public awareness about the dangers of heavy metal exposure through contaminated water and provides baseline data that can support future research, risk assessment, and sustainable water resource management in Kaduna South Metropolis and similar settings.

This study aimed to evaluate and compare heavy metal contamination in river, borehole, and well water sources in Kaduna South metropolis, Nigeria and then compare the results with the drinking water standards of the World Health Organization (WHO).

The goal of this work is to evaluate the water quality of each source based on the concentrations of heavy metals and compare them to national and international standards and determine the potential sources of heavy metals contamination in each water source, such as industrial activities, agricultural runoff, or natural geological process.

The scope of this study is further confined to a single sampling period, and therefore seasonal variations in heavy metal concentrations were not considered. Despite these boundaries, the study provides reliable baseline data on the level of heavy metal contamination in major water sources within Kaduna South Metropolis and serves as a reference point for future research, policy formulation, and water quality management in the area.

2. LITERATURE REVIEW

2.1 Overview of Heavy Metal Contamination in Water

Heavy metal contamination of water resources has emerged as a critical environmental and public health concern globally, particularly in developing countries experiencing rapid urbanization and industrial growth. Heavy metals are generally defined as metallic elements with high atomic weight and density that exhibit toxicity even at low concentrations. While certain metals such as iron (Fe) and zinc (Zn) are essential micronutrients required for normal physiological functions, excessive exposure can result in adverse health effects. Conversely, metals such as lead (Pb) and cadmium (Cd) have no known biological benefit and are considered highly toxic to humans (Duffus, 2002; Tchounwou et al., 2012).

In Nigeria, numerous studies have documented the presence of elevated heavy metal concentrations in both surface and groundwater sources. Abdullahi et al. (2019) conducted a comparative assessment of river, borehole, and well water in Zaria, Kaduna State, reporting lead concentrations above the World Health Organization (WHO) guideline values across all sampled sources. Their findings indicated that river water exhibited the highest contamination levels, reflecting the influence of anthropogenic activities such as industrial effluent discharge, urban runoff, and improper waste disposal.

2.2 Review of Related Study

Danladi (2018) evaluated heavy metal concentrations in surface and groundwater sources in industrial zones of Kaduna South Local Government Area. The study revealed that concentrations of lead, cadmium, chromium, and iron in river and well water exceeded WHO drinking water standards, while borehole water generally exhibited lower metal levels. These results emphasized the contribution of industrial processes, particularly metal fabrication and tannery operations, to heavy metal pollution of local water resources.

Similarly, Yusuf et al. (2020) investigated heavy metal contamination in water sources within Kaduna Metropolis and observed consistently higher concentrations of lead and iron in river and well water compared to borehole water. Although zinc and copper levels remained within WHO permissible limits, the elevated concentrations of lead posed significant public health concerns. The authors attributed these contamination patterns to industrial activities, agricultural runoff, and poor waste management practices prevalent in the study area.

Focused investigations on River Kaduna by Abdullahi and Musa (2018) further demonstrated the spatial variability of heavy metal contamination. Their upstream–downstream comparative analysis showed significantly higher concentrations of lead, chromium, and iron downstream of industrial discharge points. This pattern strongly suggests anthropogenic inputs as the dominant source of contamination, while relatively lower upstream concentrations indicated limited influence from natural geological processes.

2.3 Sources of Heavy Metal Contamination

The sources of heavy metal contamination in aquatic environments are broadly classified into natural and anthropogenic origins. Natural sources include weathering of metal-bearing rocks and soil erosion, which can introduce elements such as iron and chromium into groundwater systems. Anthropogenic sources encompass industrial effluents, agricultural runoff from fertilizer and pesticide application, corrosion of metal pipelines, and leachates from improperly managed municipal waste sites (Wuana & Okieimen, 2011; Ali et al., 2019).

2.4 Health Effects of Heavy Metals

Exposure to heavy metals through contaminated drinking water has been associated with a wide range of adverse health outcomes. Chronic lead exposure is linked to neurological impairment, developmental deficits in children, and renal dysfunction. Cadmium exposure is associated with kidney damage, skeletal disorders, and carcinogenic effects, while excessive iron intake may result in liver damage and cardiovascular complications (Kabata-Pendias, 2011; WHO, 2017). These health implications underscore the necessity for rigorous monitoring and regulation of drinking water quality.

Summarily, the reviewed literature demonstrates a consistent pattern of heavy metal contamination in water

sources within Kaduna Metropolis and comparable urban-industrial settings. However, many existing studies focus on either surface water or groundwater in isolation. A comparative evaluation of river, borehole, and well water within the same geographical context, as undertaken in the present study, is therefore essential for identifying relative contamination levels, elucidating potential sources of pollution, and providing robust baseline data for water resource management and public health policy formulation.

3. METHODOLOGY

The study was conducted in Kaduna South Metropolis, Kaduna State, Nigeria, an urban area characterized by intensive industrial activities, rapid population growth, and increasing pressure on surface and groundwater resources. Sampling locations were selected within Nasarawa and Kabala districts, representing residential, commercial, and industrial settings where river, borehole, and well water are commonly used for domestic purposes.

A comparative cross-sectional research design was adopted to evaluate and compare the concentrations of selected heavy metals in river, borehole, and well water. This design enabled the assessment of spatial variation in heavy metal contamination across different water sources within the same geographical location.

3.1 SAMPLE COLLECTION, PRESERVATION AND DIGESTION

Water samples were collected from three representative sources: one river site, one borehole, and one hand-dug well. At each site, 500 mL of water was collected using pre-cleaned polyethylene sampling bottles. Prior to sampling, the bottles were thoroughly washed with detergent, rinsed with distilled water, and finally rinsed with the sampled water to prevent contamination. Samples were properly labeled and transported to the laboratory for analysis.

Immediately after collection, water samples were preserved by acidification using concentrated nitric acid to maintain pH below 2 and prevent metal precipitation or microbial activity. For digestion, 50 mL of each sample was measured into a conical flask, followed by the addition of a nitric acid–hydrochloric acid mixture (3:1 ratio). The mixture was heated gently until a clear solution was obtained. After cooling, the digested samples were filtered and diluted with distilled water to a final volume of 50 mL.

3.2 Laboratory Analysis

The concentrations of zinc (Zn), cadmium (Cd), lead (Pb), chromium (Cr), and iron (Fe) were determined using Atomic Absorption Spectrophotometry (AAS) at the Science Laboratory of Ahmadu Bello University, Zaria. The instrument was calibrated using certified standard solutions for each metal, and analytical blanks were analyzed to ensure accuracy and reliability of the measurements.

3.3 Data Analysis

Measured concentrations of heavy metals were expressed in milligrams per liter (mg/L). Descriptive statistics were used to summarize the data, and the results were compared with World Health Organization (WHO) drinking water guideline values to evaluate the suitability of each water source for human consumption.

4. RESULTS AND DISCUSSION

The concentrations of Zinc (Zn), Cadmium (Cd), Lead (Pb), Chromium (Cr), and Iron (Fe) in borehole, river, and well water samples were compared against the World Health Organization (WHO) permissible limits for drinking water. The results are presented in table 4.1, while table 4.2 compares the findings with previous studies and World Health Organization (WHO) standards as shown below.

Table 4.1. Concentration of Heavy Metals in Water Sources Compared to WHO Standards

ELEMENT	Borehole (mg/L)	River (mg/L)	Well (mg/L)	WHO Limit (mg/L)
Zn	0.161	0.089	0.144	3.000
Cd	4.138	0.127	0.049	0.003
Pb	0.012	0.046	0.028	0.010
Cr	0.060	0.084	0.053	0.050
Fe	0.464	13.431	0.763	0.300

Table 4.2. Comparison of present study results with literature and WHO standards

Heavy metal	Present study (mg/L)	Abdullahi et al. (2018) (mg/L)	Yusuf et al. (2020) (mg/L)	Danladi (2018) (mg/L)	World Health Organisation (WHO) Limit (mg/L)
Zinc (Zn)	Borehole 0.161	Borehole 0.9	Borehole 0.9	—	3.0
	River 0.089	River 0.85	River 1.5	—	
	Well 0.144	Well 0.9	Well 1.1	—	
Cadmium (Cd)	Borehole 4.138	—	—	Borehole 0.005	0.003
	River 0.127	—	—	River 0.02	
	Well 0.049	—	—	Well 0.015	
Lead (Pb)	Borehole 0.012	Borehole 0.05	Borehole 0.04	Borehole 0.04	0.01
	River 0.046	River 0.25	River 0.21	River 0.18	
	Well 0.028	Well 0.12	Well 0.15	Well 0.11	
Chromium (Cr)	Borehole 0.060	—	—	Borehole 0.02	0.05
	River 0.084	—	—	River 0.06	
	Well 0.053	—	—	Well 0.04	
Iron (Fe)	Borehole 0.464	Borehole 0.9	Borehole 0.32	Borehole 0.5	0.3
	River 13.431	River 1.2	River 0.55	River 0.9	
	Well 0.763	Well 1.8	Well 0.46	Well 0.7	

In table 4.1, the results show that Zinc concentrations across all water sources were within WHO permissible limits. Cadmium concentrations were critically high, particularly in borehole water. Lead, chromium, and iron concentrations exceeded WHO standards in most samples, indicating potential health risks. The contamination pattern suggests combined influences of industrial discharge, agricultural runoff, and geological formations.

The comparison in table 4.2 highlights that except Zinc, most heavy metal levels in the current study are higher than those recorded in the previous years. This indicates that the water sources in Kaduna South Metropolis are significantly

contaminated and unsafe for direct human consumption without treatment.

The results obtained in each water sample were compared with the World Health Organization standards as shown in figures 4.1, 4.2 and 4.3 respectively.

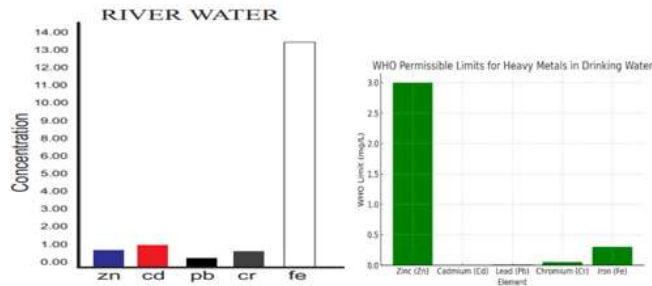


Figure 4.1. Comparison of river water results with WHO standards

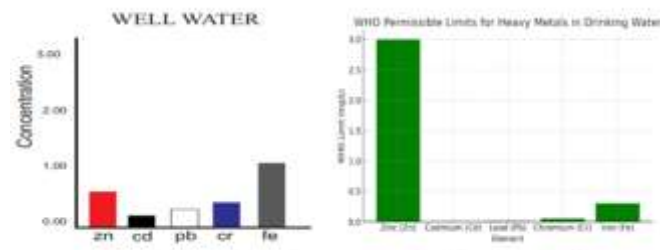


Figure 4.2. Comparison of well water results with WHO standards

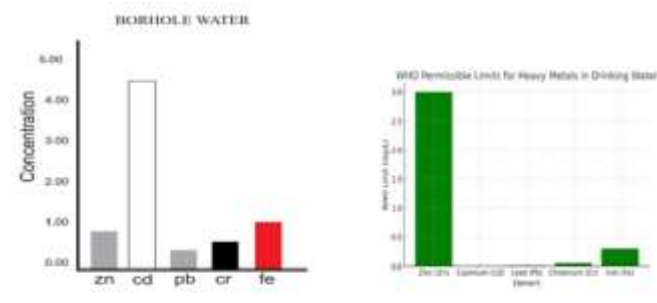


Figure 4.3. Comparison of Borehole water results with WHO standards

5. CONCLUSION AND RECOMMENDATIONS

This study revealed significant contamination of river, borehole, and well water sources in Kaduna South Metropolis with toxic heavy metals, particularly cadmium (Cd), lead (Pb), chromium (Cr), and iron (Fe), all of which exceeded the World Health Organization (WHO) permissible limits for drinking water, while zinc (Zn) remained within safe levels. The exceptionally high concentrations of Cd in borehole water and Fe in river water highlight serious public health risks associated with prolonged consumption, including kidney damage, neurological disorders, anemia, and other chronic health conditions. These findings indicate that none of the investigated water is safe for direct human consumption without adequate treatment and that anthropogenic activities such as industrial discharge, agricultural runoff, improper waste disposal, and natural geological processes are major contributors to the observed contamination.

Consequently, it is recommended that appropriate water treatment methods be implemented before domestic use, strict enforcement of environmental regulations governing industrial effluents be strengthened, and routine water quality programs be established by relevant authorities. In addition, public awareness campaigns should be intensified to educate residents on the dangers of heavy metal exposure, while government intervention in providing safe, treated municipal water supply is essential to reduce reliance on contaminated surface and groundwater sources.

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