

Geospatial Assessment of Heavy Metal Concentration in Groundwater of Kaduna South Local Government, Nigeria

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ABSTRACT

Water is an essential natural resource that supports human life, economic activities, and ecosystem functioning. However, groundwater quality is increasingly threatened by heavy metal contamination arising from anthropogenic activities. This study presents a geospatial assessment of heavy metal concentrations in groundwater within Kaduna South Local Government Area (LGA), north-western Nigeria. A total of thirty (30) groundwater samples were collected from boreholes and hand-dug wells and analysed for Zinc (Zn), Chromium (Cr), Cadmium (Cd), Lead (Pb), Iron (Fe), and Copper (Cu) using Atomic Absorption Spectrophotometry (AAS). Geographic Information System (GIS) techniques, specifically Ordinary Kriging interpolation, were employed to model spatial distribution patterns. Results revealed significant spatial variability, with elevated concentrations of Cr (0.23-0.25 mg/L), Cd (0.18-0.23 mg/L), Pb (3.65-4.73 mg/L), and Fe (3.92-7.04 mg/L) forming contamination hotspots in industrialised wards such as: Kakuri, Makera, Sabo, and Tudun Wada. In contrast, Zn (0.29-0.46 mg/L) and Cu (0.36-0.53 mg/L) remained within WHO and SON permissible limits. However, Cd, Pb, and Fe exceeded recommended thresholds in a substantial proportion of samples, indicating potential public health risks. The spatial patterns suggest strong anthropogenic influence, including industrial discharge, poor waste management, and infrastructure deterioration. This study demonstrates the effectiveness of geospatial techniques in groundwater quality assessment and provides critical data for sustainable groundwater management and public health protection.

Keywords: Groundwater; Heavy metals; Ordinary Kriging; Geospatial; Kaduna South

1.0 INTRODUCTION

Groundwater is one of the most critical freshwater resources globally, supporting domestic, agricultural and industrial water demands, particularly in rapidly urbanising regions (Gleick, 2020; Rashid *et al.*, 2023). In many developing countries, groundwater constitutes the primary source of potable water due to its relative accessibility and perceived quality (Opafola *et al.*, 2020; United Nations Environment Programme [UNEP], 2021). However, increasing urbanisation, industrialisation and poor waste management practices have intensified the risk of groundwater contamination, especially by heavy metals. In Nigeria, groundwater pollution has been widely reported, with studies highlighting the use of pollution indices in assessing heavy metal contamination and associated risks (Adesakin *et al.*, 2020).

Heavy metals such as chromium, cadmium, lead and nickel are of particular concern because of their persistence, toxicity and tendency to bioaccumulate in human tissues. Chronic exposure to these metals through drinking water consumption has been linked to kidney dysfunction, neurological disorders, skeletal damage and carcinogenic effects. According to the World Health Organization (WHO, 2022), drinking water

contaminated with heavy metals beyond permissible limits poses significant public health risks, especially to children and pregnant women.

Geospatial techniques, particularly Geographic Information Systems (GIS) and geostatistical interpolation methods, have become increasingly important in environmental monitoring. These tools enable the spatial visualisation of contamination patterns, identification of pollution hotspots and assessment of spatial relationships between contaminant sources and affected areas (Li *et al.*, 2021; Burrough *et al.*, 2015). Ordinary Kriging, in particular, has been widely applied in groundwater quality studies due to its ability to account for spatial autocorrelation in environmental datasets.

Kaduna South Local Government Area represents a typical urban-industrial setting where extensive industrial activities, high population density and dependence on groundwater coexist (Abubakar *et al.*, 2021; Owamah *et al.*, 2023). Despite the reliance on groundwater for domestic use, systematic geospatial assessments of heavy metal concentration in the area remain limited. This study therefore, applies GIS-based

techniques to assess the spatial distribution and severity of heavy metal concentration in groundwater across Kaduna South LGA, evaluating compliance with WHO and SON drinking water standards with the aim of providing scientific evidence to support groundwater management and public health decision-making.

Kaduna South Local Government Area is located between Latitudes 10°26'00" N and 10°34'00" North of the Equator and Longitudes 7°22'00"E and 7°27'00" East of the Greenwich Meridian (Figure 1). It is bordered to the north by Kaduna North LGA, to the south by Chikun LGA, to the east by Igabi LGA, and to the west by Kajuru LGA. Kaduna South Local Government Area covers a land area of 59 km² (Figure 1). The area is characterised by intense industrial activity, dense residential settlements and widespread dependence on groundwater sources such as boreholes and hand-dug wells. The underlying geology is dominated by Precambrian Basement Complex rocks, which influence groundwater occurrence, flow and geochemical characteristics. Industrial estates, abattoirs, automobile workshops and waste dumpsites are common features within the area and represent potential sources of groundwater contamination. In addition, the drainage network, comprising both natural channels and open stormwater drains, facilitates the transport of contaminants into subsurface water systems, particularly during the rainy season (NGSA, 2023).

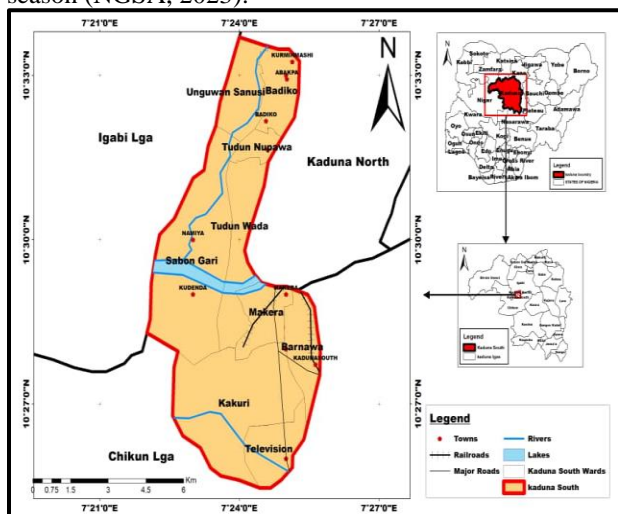


Figure 1: Study Area Map

2.0 MATERIAL AND METHODS

2.1 Types and Source of Data

Thirty (30) groundwater samples were purposively collected from boreholes and hand-dug wells across the

study area: This was done to reflect varying land-use characteristics and proximity to potential pollution sources. Geographic coordinates of each sampling point were recorded using a handheld Global Positioning System (GPS) receiver.

Water samples were collected in pre-cleaned polyethylene bottles and preserved following standard procedures. Samples were acidified with nitric acid to prevent metal precipitation and adsorption prior to laboratory analysis. Concentrations of Zn, Cr, Cd, Pb, Fe and Cu were determined using Atomic Absorption Spectrophotometry (AAS). Quality control measures included instrument calibration, reagent blanks and duplicate sample analysis to ensure analytical accuracy.

2.2 Data Analysis

The laboratory-derived heavy metal concentrations were integrated with spatial coordinates and analysed using ArcGIS 10.8 software (ESRI, 2021). Ordinary Kriging interpolation was applied to generate continuous spatial distribution maps for each heavy metal. This method was selected due to its suitability for environmental datasets exhibiting spatial autocorrelation and it's widely applied in recent groundwater studies due to its robustness in modelling spatial autocorrelation (Rahman *et al.*, 2021; Karim *et al.*, 2024). Interpolated concentration surfaces were reclassified into five contamination classes (very low, low, moderate, high and very high) using natural break (Jenks) classification to enhance spatial interpretation and hotspot identification.

3.0 RESULTS AND DISCUSSION

3.1 Metal Concentrations in Relations to WHO and SON Limits

The statistical summary of heavy metal concentrations in groundwater samples from Kaduna South LGA is presented in Table 1. Zinc (0.214) and Copper (0.187) recorded mean concentrations below the WHO and SON permissible limits, indicating acceptable water quality with respect to these metals. In contrast, other metals in the study exhibited mean concentrations that exceeded recommended guideline values, reflecting significant contamination levels.

Lead exhibited a 100% exceedance rate across sampled locations, indicating widespread contamination. Iron concentrations were also markedly elevated in most locations, suggesting combined geogenic and anthropogenic influences.

Table 1: Metal Concentrations in Relations to WHO and SON limits (mg/L)

Metal	Min	Max	Mean	Std. Dev	WHO Limit	SON Limit	% Exceedance
Zn	0.042	0.641	0.214	0.131	3.0	3.0	0
Cu	0.029	0.550	0.187	0.102	2.0	1.0	0
Cr	0.006	0.408	0.129	0.097	0.05	0.05	46.7
Cd	0.001	0.231	0.082	0.061	0.003	0.003	73.3
Fe	0.922	10.706	3.842	2.117	0.3	0.3	86.7
Pb	0.19	4.811	1.926	1.208	0.01	0.01	100

3.2 Spatial Concentrations of the Metals in the Study Area

The concentration patterns for Zinc (Zn) and Copper (Cu) are presented in Figures 2.

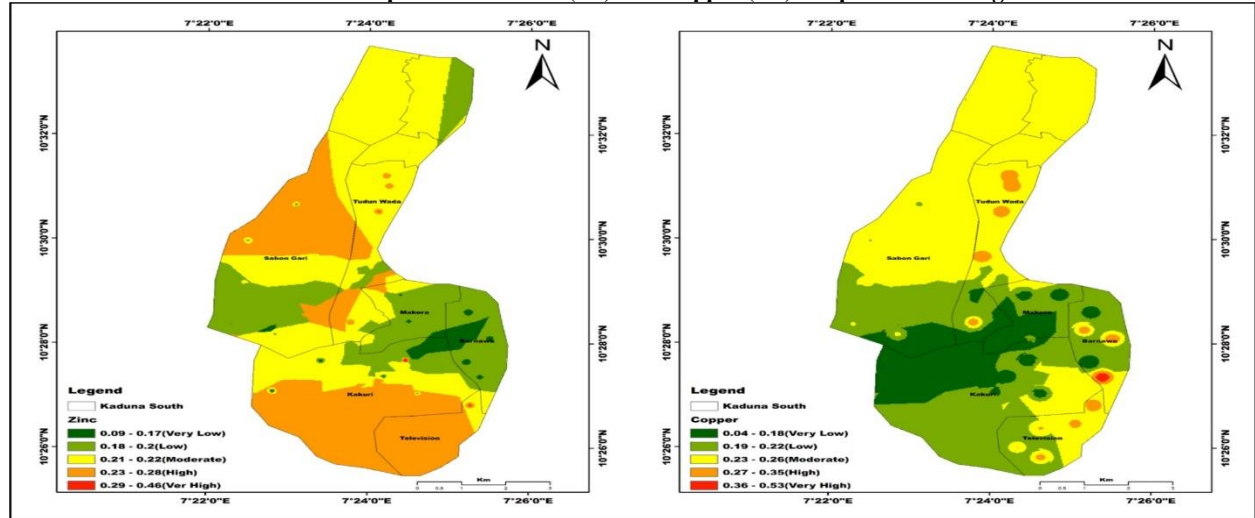


Figure 2: Spatial distribution of Zn and Cu concentration in groundwater of Kaduna South LGA.

Zinc concentrations exhibited relatively uniform spatial patterns across Kaduna South LGA, with slightly elevated values of 0.29 mg/L to 0.46 mg/L in Kakuri and Makera wards. However, all other areas remained within permissible drinking water limits. Copper concentrations displayed a similar spatial pattern with very high (0.36-0.53 mg/L) predominantly in Makera, Kakuri and parts of Sabon Gari. The absence of significant contamination hotspots for Zn and Cu indicates limited anthropogenic enrichment and minimal health risk associated with these metals. Although Zinc and Copper remained within permissible limits (Table 1), their elevated concentrations in certain locations suggest ongoing influence from pipe corrosion and surface runoff.

Figure 3 shows the concentration patterns of Chromium and Cadmium in the study area.

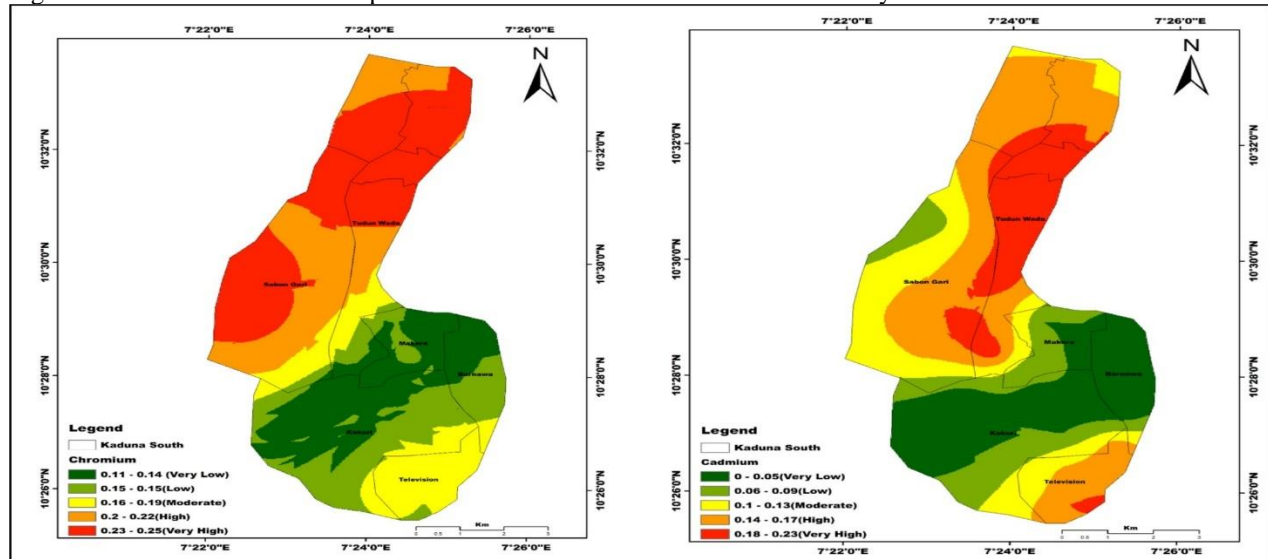
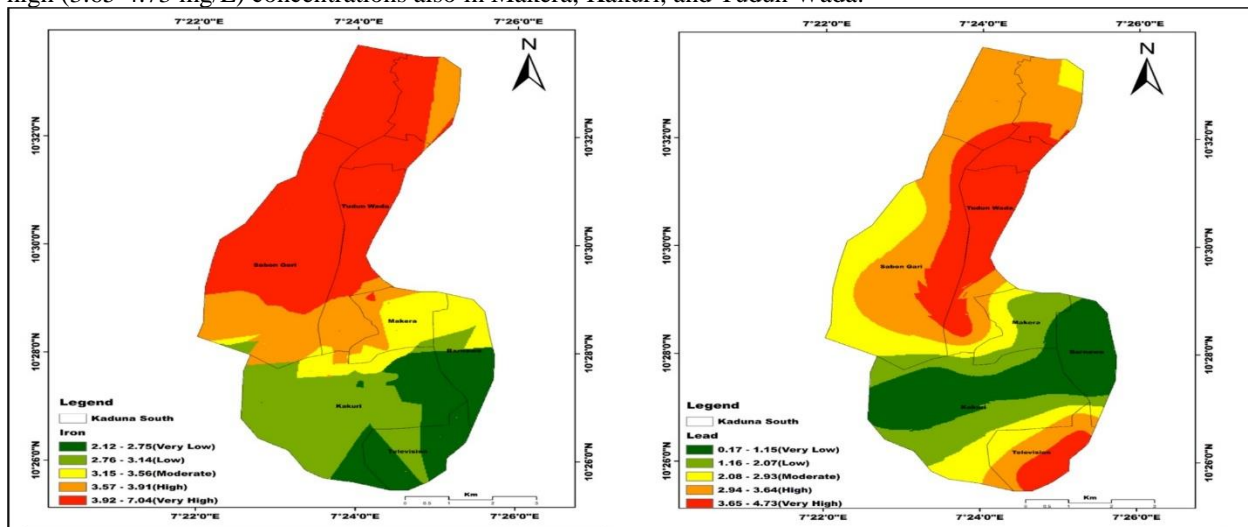


Figure 3: Spatial distribution of Cr and Cd concentration in groundwater of Kaduna South LGA.

The spatial concentration of Chromium (Cr) in groundwater across Kaduna South LGA displays clear variation across the wards. The values range from very low (0.11-0.14 mg/L) to very high (0.23-0.25 mg/L). Areas such as Makera, Kakuri and parts of Sabon Gari show very high-to-high concentrations. The concentration levels of Cadmium, like chromium indicated Makera and part of Kakuri to have been recorded very high (0.18-0.23 mg/L) concentration. The appearance of high concentration level of these metals in Makera and Kakuri may be associated with high levels of industrial activity in the areas. The values of Cd across the study area for instance exceed WHO threshold by a wide margin, with some locations recording concentrations over 70 times the safe limit. This suggests a widespread and critical contamination of groundwater with Cadmium, posing serious risks to public health, particularly kidney damage, bone toxicity, and carcinogenic effects with long-term exposure.

Figure 4 presents findings on the concentration of Iron (Fe) and Lead (Pb) in the study area. The spatial concentration of iron metal in the groundwater of the area reveals distinct spatial variability. The results indicated that, while some areas recorded very low (2.12-2.75 mg/L) concentration, Kakuri, Makera and part of Sabon Gari recorded very high (3.92-7.04 mg/L) concentration. The highest concentrations may be linked to dense industrial activities, indiscriminate waste disposal and potential leaching from iron-rich lithological units. Hence, these areas exhibit values exceeding the WHO permissible limit for iron in drinking water. In contrast, lower concentrations are evident in Barnawa, suggesting either minimal anthropogenic influence or effective groundwater recharge and dilution mechanisms in these zones. The spatial variation of lead concentration in the area indicates significant spatial variability, with very high (3.65-4.73 mg/L) concentrations also in Makera, Kakuri, and Tudun Wada.

**Figure 4: Spatial distribution of Fe and Pb concentration in groundwater of Kaduna South LGA.**

The observed spatial variability in heavy metal concentrations reflects the combined influence of anthropogenic activities and local hydrogeological conditions. Industrial operations, waste disposal practices and aging water infrastructure appear to be the dominant contributors to elevated metal concentrations in industrialised wards. The pronounced clustering of elevated Cadmium, Lead, and Chromium concentrations in Kakuri, Makera, Sabo and Tudun Wada wards corresponds spatially with industrial estates, automobile workshops, abattoirs and waste disposal sites, indicating strong source-pathway-receptor relationships. This strongly supports the role of anthropogenic activities as the primary drivers of groundwater contamination.

Comparable spatial contamination patterns have been reported in other urban-industrial environments in Nigeria and sub-Saharan Africa, where industrial discharge, poor waste management and informal industrial operations contribute significantly to groundwater degradation Ogbeide *et al.* (2024). Studies by Oyem *et al.* (2024) and Nwankwoala *et al.* (2019) similarly reported elevated heavy metal concentrations in groundwater within rapidly urbanising environments, reinforcing the regional relevance of the observed patterns. The findings of this study align with those reported by Rehman *et al.* (2018), who investigated the toxicological implications of heavy metal contamination

in groundwater across multiple regions, including parts of Nigeria. Their work identified lead (Pb), cadmium (Cd), mercury (Hg), and chromium (Cr) as priority pollutants due to their persistence in the environment and tendency to bioaccumulate in human tissues. These results are also consistent with those of Ideriah *et al.* (2024), who reported elevated levels of Pb, Cd, and Fe in groundwater in Nigeria. Their research revealed significant variations in Pb, Cd, and Fe concentrations across different locations, with some sites exceeding WHO drinking water standards. In the present study, cadmium and lead concentrations significantly exceeded WHO guidelines, indicating a critical level of contamination and potential long-term health risks. According to Tchounwou *et al.* (2021), prolonged exposure to such metals may result in bioaccumulation and severe health complications.

4.0 CONCLUSION AND RECOMMENDATIONS

This study demonstrates the effectiveness of geospatial techniques in assessing groundwater heavy metal contamination in an urban-industrial environment. The results indicate that while Zinc and Copper concentrations remain within acceptable limits, Cadmium, Lead, Chromium and Iron exceed WHO and SON permissible limits in several wards of Kaduna South LGA. The highest contamination levels were consistently observed in industrialised areas, highlighting the dominant influence of anthropogenic activities such as industrial discharge, improper waste disposal and infrastructure corrosion.

The identification of contamination hotspots provides critical spatial information for targeted groundwater remediation and regulatory intervention. Regular groundwater monitoring, enforcement of environmental regulations and improvements in waste management practices are strongly recommended to safeguard public health and promote sustainable groundwater use in Kaduna South Local Government Area.

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