

GEO-SPATIAL ANALYSIS OF GROUNDWATER QUALITY AND HEAVY METAL CONTAMINATION IN PERI-URBAN COMMUNITIES OF LAGOS AND OGUN STATES

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Abstract

Groundwater remains the primary source of drinking water for many peri-urban communities in Nigeria, yet its quality is increasingly threatened by anthropogenic contamination. This study investigates the spatial distribution and health implications of heavy metal contamination in groundwater across selected peri-urban communities in Lagos and Ogun States. A cross-sectional analytical design was adopted, integrating field sampling, laboratory analysis, and geospatial techniques. Groundwater samples ($n = 120$) were collected from wells and boreholes across twelve communities and analyzed for physicochemical parameters and heavy metals (Pb, Cd, Cr, As, Hg) using Atomic Absorption Spectrophotometry (AAS) and ICP-MS. Spatial mapping was conducted using ArcGIS, while statistical analyses, including correlation and regression, were performed using SPSS. Results indicate that mean concentrations of Pb (0.021 mg/L), Cd (0.008 mg/L), and As (0.015 mg/L) exceeded WHO permissible limits in several locations. GIS mapping revealed distinct contamination hotspots near industrial clusters and waste disposal sites. Health risk assessment showed Hazard Quotient (HQ) values above 1 for Pb and Cd in 58% of sampled locations, indicating significant non-carcinogenic risks. The study concludes that groundwater in peri-urban Lagos and Ogun is compromised and poses serious public health threats. Policy interventions, including stricter environmental regulation and community-based water treatment strategies, are recommended.

Keywords: Groundwater quality, Heavy metals, GIS, Health risk assessment, Peri-urban communities, Nigeria

1. Introduction

Access to safe and potable water remains a fundamental determinant of public health, environmental sustainability, and socio-economic development, particularly in rapidly urbanizing regions of the Global South. In Nigeria, groundwater constitutes the primary source of domestic water supply in many peri-urban communities due to inadequate municipal water infrastructure and increasing population pressure (UNESCO, 2023; World Health Organization [WHO], 2022). In Lagos and Ogun States, the expansion of peri-urban settlements has intensified reliance on shallow aquifers accessed through boreholes and hand-dug wells. However, this critical resource is increasingly threatened by contamination arising from anthropogenic activities such as industrial discharge, agricultural runoff, and indiscriminate waste disposal (Afolabi et al., 2023; Adewumi et al., 2023).

Heavy metal contamination represents one of the most significant threats to groundwater quality due to the persistent, non-biodegradable, and bioaccumulative nature of these pollutants. Toxic metals such as lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), and chromium (Cr) can infiltrate groundwater systems through industrial effluents, leachates from dumpsites, and poorly managed sanitation infrastructure (Bello et al., 2022; Li et al., 2021). Empirical studies conducted in various parts of Nigeria and other developing countries have reported elevated concentrations of these metals in groundwater sources, often exceeding the permissible limits recommended by international standards (Ajayi et al., 2021; Obasi et al., 2023). Exposure to such contaminants has been associated with severe health outcomes, including neurological impairment, kidney dysfunction, cardiovascular diseases, and increased risk of cancer, particularly among vulnerable populations such as children and pregnant women (WHO, 2022; Tchounwou et al., 2021).

The rapid and often unregulated expansion of peri-urban environments further exacerbates groundwater vulnerability. These areas are typically characterized by weak environmental governance, inadequate waste management systems, and informal land-use practices, all of which contribute to increased contamination risks (Akinyemi & Fasuyi, 2022; Ajibade et al., 2021). Studies have demonstrated that groundwater quality deterioration is strongly correlated with proximity to industrial zones, waste dumps, and agricultural activities, highlighting the spatial dimension of contamination processes (Nwankwo et al., 2021; Adebayo & Lawal, 2020). In addition, climate variability and seasonal fluctuations influence hydrogeological conditions, often leading to the concentration or mobilization of heavy metals within aquifers, particularly during dry and flood periods (Adewumi et al., 2023; Kumar et al., 2022).

In recent years, the integration of Geographic Information Systems (GIS) and spatial analytical techniques has significantly enhanced the capacity for environmental monitoring and groundwater quality assessment. GIS-based approaches enable the visualization of spatial variability, identification of contamination hotspots, and modelling of environmental risks, thereby providing critical insights for evidence-based decision-making (Nwachukwu et al., 2020; Rahman et al., 2021). When combined with hydrochemical analysis and statistical modelling, geospatial tools offer a robust framework for understanding complex interactions between environmental factors and groundwater contamination patterns. Such interdisciplinary approaches are increasingly recognized as essential for sustainable water resource management, particularly in data-scarce and rapidly changing environments.

Despite the growing body of literature on groundwater contamination, there remains a significant gap in comprehensive, geo-referenced studies that integrate hydrochemical analysis, spatial distribution, and human health risk assessment in peri-urban Nigeria. Many existing studies are limited in scope, focusing either on localized assessments or single analytical dimensions, thereby constraining their applicability for large-scale planning and policy formulation (Ogundele et al., 2022; Nwankwo et al., 2021). Consequently, there is an urgent need for holistic and spatially explicit investigations that provide actionable insights into groundwater contamination dynamics and their implications for public health.

Against this backdrop, this study undertakes a geo-spatial analysis of groundwater quality and heavy metal contamination in selected peri-urban communities of Lagos and Ogun States. By integrating field-based water sampling, advanced laboratory techniques, and GIS-driven spatial modelling, the study aims to generate high-resolution contamination maps, assess associated health risks, and identify key environmental drivers of groundwater pollution. The findings are expected to contribute to the growing body of knowledge on groundwater sustainability while providing a scientific basis for targeted policy interventions, environmental regulation, and community-level water safety strategies in Nigeria and similar developing contexts.

2. Literature Review

Groundwater contamination has become a major environmental and public health concern globally, particularly in rapidly urbanizing regions where anthropogenic pressures are intense. Groundwater systems are highly vulnerable to contamination due to their interaction with surface activities, including industrial processes, agricultural practices, and domestic waste disposal (Li et al., 2021; Selvam et al., 2022). In developing countries such as Nigeria, inadequate environmental regulation and poor waste management infrastructure exacerbate the infiltration of pollutants into aquifers, thereby compromising water quality (Bello et al., 2022; Egbueri & Unigwe, 2020). Peri-urban areas are especially susceptible due to their transitional nature between rural and urban systems. These zones often experience unplanned development, resulting in the proliferation of informal settlements, septic systems, and open dumpsites, all of which contribute to groundwater degradation (Akinyemi & Fasuyi, 2022; Ajibade et al., 2021). Consequently, groundwater in these regions is increasingly exposed to both point and non-point sources of contamination, making comprehensive monitoring and management imperative.

Heavy metals are among the most hazardous contaminants in groundwater due to their toxicity, persistence, and bioaccumulation potential. Unlike organic pollutants, heavy metals do not degrade over time and can accumulate in living organisms, leading to long-term ecological and health impacts (Tchounwou et al., 2021). Common heavy metals of concern in groundwater include lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg), and chromium (Cr), all of which have been widely reported in environmental studies across Africa and other developing regions (Obasi et al., 2023; Wu et al., 2020). In Nigeria, several studies have documented elevated levels of heavy metals in groundwater sources, particularly in areas with high industrial and agricultural activities. Ajayi et al. (2021) reported significant concentrations of lead and cadmium in groundwater samples from industrial zones, while Olalekan and Olayinka (2022) observed widespread contamination linked to improper waste disposal practices. These findings are consistent with global trends, where industrial effluents, mining activities, and agricultural chemicals have been

identified as major sources of heavy metal pollution (Li et al., 2021; Rahman et al., 2021). The health implications of heavy metal exposure are profound. Lead exposure, for instance, has been associated with cognitive impairment and developmental delays in children, while cadmium is known to cause kidney damage and skeletal disorders. Arsenic exposure is particularly concerning due to its carcinogenic properties, with long-term ingestion linked to skin, lung, and bladder cancers (WHO, 2022; Tchounwou et al., 2021). These health risks underscore the need for continuous monitoring and mitigation of heavy metal contamination in groundwater systems.

The application of geospatial technologies, particularly Geographic Information Systems (GIS), has significantly advanced the study of groundwater quality and contamination dynamics. GIS provides a powerful platform for integrating spatial and non-spatial data, enabling the visualization, analysis, and interpretation of environmental phenomena (Nwachukwu et al., 2020; Rahman et al., 2021). Recent studies have demonstrated the effectiveness of GIS in mapping groundwater contamination and identifying pollution hotspots. For example, Nwankwo et al. (2021) utilized GIS-based interpolation techniques to map heavy metal distribution in groundwater, revealing significant spatial variability linked to industrial and residential activities. Similarly, Adebayo and Lawal (2020) employed remote sensing and GIS tools to assess the impact of industrial effluents on groundwater quality in urban environments. In addition to spatial mapping, GIS-based models have been used to assess groundwater vulnerability and predict contamination risks. Techniques such as the DRASTIC model and water quality index (WQI) mapping have been widely applied to evaluate aquifer susceptibility and guide resource management decisions (Kumar et al., 2022; Selvam et al., 2022). These approaches provide valuable insights for policymakers by identifying high-risk areas and prioritizing intervention strategies.

Groundwater contamination is influenced by a combination of environmental and anthropogenic factors. Industrial activities, including manufacturing, mining, and oil refining, are major contributors to heavy metal pollution through the discharge of untreated or poorly treated effluents (Li et al., 2021; Bello et al., 2022). Similarly, agricultural practices involving the use of fertilizers and pesticides introduce contaminants such as nitrates and heavy metals into groundwater systems (Wu et al., 2020). Urbanization also plays a critical role in groundwater degradation. The expansion of urban and peri-urban areas often leads to increased waste generation, inadequate sanitation systems, and higher demand for water resources, all of which contribute to contamination (Akinyemi & Fasuyi, 2022; Ajibade et al., 2021). Furthermore, climate variability influences groundwater quality by altering hydrological processes. Seasonal fluctuations in rainfall and temperature can affect the mobilization, dilution, and concentration of contaminants within aquifers (Adewumi et al., 2023; Kumar et al., 2022). The interaction of these factors creates complex contamination patterns that vary spatially and temporally, necessitating integrated analytical approaches that combine environmental, chemical, and spatial data.

Health risk assessment is a critical component of groundwater quality studies, as it provides a quantitative measure of the potential impacts of contaminants on human health. The Hazard Quotient (HQ) and Hazard Index (HI) are commonly used indicators for assessing non-carcinogenic risks associated with exposure to contaminated water (USEPA, 2022; Tchounwou et al., 2021). An HQ value greater than 1 indicates a potential health risk, while the HI represents the cumulative risk from multiple contaminants. Several studies have applied these models to evaluate

the health implications of groundwater contamination. For instance, Rahman et al. (2021) found that HQ values for lead and arsenic exceeded safe limits in several communities, indicating significant health risks. Similarly, Egbueri and Unigwe (2020) reported elevated health risk indices in areas affected by industrial pollution in Nigeria. The integration of health risk assessment with geospatial analysis enhances the ability to identify high-risk populations and prioritize intervention strategies. By mapping risk zones and linking them to contamination sources, policymakers can develop targeted approaches to mitigate exposure and improve public health outcomes.

Despite the growing body of literature on groundwater contamination and heavy metal pollution, significant gaps remain in the context of peri-urban Nigeria. Many existing studies are limited in scope, focusing on either hydrochemical analysis or spatial distribution without integrating both dimensions with health risk assessment (Ogundele et al., 2022; Nwankwo et al., 2021). Furthermore, there is a lack of high-resolution, geo-referenced datasets that can support evidence-based decision-making at local and regional levels. This study addresses these gaps by adopting an integrated approach that combines groundwater sampling, laboratory analysis, GIS-based spatial modelling, and health risk assessment. By providing a comprehensive understanding of contamination patterns and their implications, the study contributes to the advancement of knowledge in environmental monitoring and supports the development of sustainable water management strategies in peri-urban Nigeria.

3. Methodology

This study employed a cross-sectional analytical design integrating hydrochemical assessment, geospatial analysis, and advanced multivariate modelling to examine groundwater quality and heavy metal contamination in selected peri-urban communities of Lagos and Ogun States, Nigeria. Twelve communities (six per state) were purposively selected based on population density, proximity to industrial activities, and reported environmental risks, while a total of 120 groundwater samples from wells and boreholes were obtained using a stratified sampling approach to ensure spatial representativeness and statistical adequacy for multivariate analysis (Hair et al., 2022; Rahman et al., 2021). Water samples were collected in accordance with World Health Organization protocols (WHO, 2022) and analyzed for physicochemical parameters (pH, electrical conductivity, total dissolved solids, and turbidity) and heavy metals (Pb, Cd, As, Hg, and Cr) using Atomic Absorption Spectrophotometry (AAS) and Inductively Coupled Plasma Mass Spectrometry (ICP-MS), with strict quality control measures including calibration standards, duplicate sampling, and blank analyses to ensure reliability (Skoog et al., 2021). Geographic coordinates of sampling points were captured using GPS and processed in ArcGIS 10.8 to generate spatial distribution maps, while spatial interpolation techniques such as Inverse Distance Weighting and Ordinary Kriging were applied to identify contamination hotspots and spatial variability patterns (Selvam et al., 2022; Kumar et al., 2022). To achieve robust analytical depth, the study integrated Partial Least Squares Structural Equation Modelling (PLS-SEM) to evaluate the relationships among latent constructs—Anthropogenic Activities, Environmental Factors, Groundwater Contamination, and Health Risk—where measurement model reliability and validity were assessed using Cronbach's alpha, composite reliability, and average variance extracted, and structural relationships were tested through bootstrapping procedures (Hair et al., 2022; Kline, 2023). Complementary statistical analyses, including descriptive statistics, Pearson correlation, multiple regression, and Principal Component Analysis, were conducted using SPSS version 27

and R software to identify contamination patterns and sources (Li et al., 2021). Health risk assessment was performed using the United States Environmental Protection Agency model by computing Chronic Daily Intake, Hazard Quotient, and Hazard Index values to determine non-carcinogenic risks associated with groundwater consumption, where values greater than one indicate significant health concerns (USEPA, 2022; Tchounwou et al., 2021). Ethical approval was obtained, community consent was secured, and robustness checks including multicollinearity diagnostics, normality testing, and SEM model fit indices were conducted to ensure validity, reliability, and generalizability of the findings.

4. Results and Discussion

Table 1: Descriptive Statistics of Heavy Metal Concentrations in Groundwater (mg/L)

Parameter	Mean	WHO Limit	Std. Dev	Min	Max
Pb	0.021	0.010	0.008	0.006	0.038
Cd	0.008	0.003	0.004	0.002	0.017
As	0.015	0.010	0.006	0.004	0.028
Cr	0.042	0.050	0.010	0.020	0.061
Hg	0.004	0.006	0.002	0.001	0.007

Table 1 presents the descriptive statistics of heavy metal concentrations in groundwater across the sampled peri-urban communities. The results indicate that the mean concentrations of lead (Pb = 0.021 mg/L), cadmium (Cd = 0.008 mg/L), and arsenic (As = 0.015 mg/L) exceeded the permissible limits set by the World Health Organization (WHO, 2022), suggesting widespread contamination and potential health risks. In particular, lead concentrations were more than double the recommended threshold, highlighting severe environmental exposure likely linked to industrial emissions, battery disposal, and urban waste leachates. Cadmium levels also significantly exceeded safe limits, reflecting contributions from agricultural runoff, especially phosphate fertilizers, and industrial discharges. Arsenic concentrations above WHO limits indicate possible geogenic contributions compounded by anthropogenic activities. In contrast, chromium (Cr) and mercury (Hg) recorded mean values within permissible limits; however, their maximum values exceeded safe thresholds in some locations, suggesting localized contamination hotspots. The relatively high standard deviations across parameters indicate substantial spatial variability in contamination levels, reinforcing the need for geospatial analysis to identify high-risk zones. These findings corroborate earlier studies that reported elevated heavy metal concentrations in groundwater within rapidly urbanizing regions of Nigeria (Ajayi et al., 2021; Bello et al., 2022). Overall, the results underscore a critical environmental and public health concern, particularly for communities relying on untreated groundwater.

Table 2: Pearson Correlation Matrix of Heavy Metal Concentrations

Variable	Pb	Cd	As	Cr	Hg
Pb	1				
Cd	0.72*	1			
As	0.65*	0.68*	1		
Cr	0.41	0.52*	0.48*	1	
Hg	0.36	0.44	0.39	0.47	1

(*p < 0.05)

The correlation matrix in Table 2 reveals significant positive relationships among several heavy metals, particularly between lead and cadmium ($r = 0.72$), cadmium and arsenic ($r = 0.68$), and lead and arsenic ($r = 0.65$), all statistically significant at $p < 0.05$. These strong correlations suggest that these metals likely originate from common anthropogenic sources such as industrial effluents, urban waste disposal, and agricultural inputs. The moderate correlation between chromium and cadmium ($r = 0.52$) further supports the hypothesis of mixed pollution sources, possibly involving both industrial and natural geochemical processes. Meanwhile, weaker correlations involving mercury indicate a more heterogeneous distribution, suggesting localized contamination rather than widespread pollution. These findings align with previous environmental studies that identified strong inter-metal relationships as indicators of shared pollution pathways (Li et al., 2021; Nwankwo et al., 2021). The observed correlations provide empirical evidence supporting the role of anthropogenic activities in driving groundwater contamination in the study area.

Table 3: Multiple Regression Results for Predictors of Groundwater Contamination

Variable	Beta (β)	Std. Error	t-value	p-value
Industrial Proximity	0.61	0.117	5.21	0.000
Waste Disposal Sites	0.48	0.119	4.02	0.001
Agricultural Runoff	0.29	0.101	2.87	0.006
Constant	—	—	—	—

$R^2 = 0.68$; F-statistic = 32.45 ($p < 0.001$)

The regression results in Table 3 indicate that the selected predictors collectively explain approximately 68% of the variation in groundwater contamination ($R^2 = 0.68$), demonstrating strong model explanatory power. Industrial proximity emerged as the most significant predictor ($\beta = 0.61$, $p < 0.001$), indicating that areas closer to industrial zones exhibit higher contamination levels. This finding reflects the impact of untreated industrial discharges and improper waste management practices prevalent in peri-urban Nigeria. Waste disposal sites also showed a strong positive influence ($\beta = 0.48$, $p < 0.001$), suggesting that leachates from dumpsites significantly contribute to groundwater pollution. Agricultural runoff ($\beta = 0.29$, $p < 0.01$) further highlights the role of agrochemicals in contaminating groundwater systems, although its impact is relatively less pronounced compared to industrial activities. The statistical significance of all predictors confirms the multi-source nature of groundwater contamination, aligning with findings from Rahman et al. (2021) and Bello et al. (2022). The results emphasize the need for integrated environmental management strategies targeting multiple pollution sources.

Table 4: Hazard Quotient (HQ) and Risk Classification

Metal	HQ Value	Risk Level
Pb	1.85	High
Cd	1.42	High
As	1.21	Moderate
Cr	0.85	Low
Hg	0.67	Low

The health risk assessment results presented in Table 4 indicate that exposure to lead and cadmium poses significant non-carcinogenic risks, with Hazard Quotient (HQ) values of 1.85 and 1.42, respectively. These values exceed the threshold of 1, indicating potential adverse health effects for

populations consuming contaminated groundwater. Arsenic also recorded an HQ value above unity (1.21), suggesting moderate risk, particularly for long-term exposure. In contrast, chromium and mercury exhibited HQ values below 1, indicating relatively lower risk levels; however, cumulative exposure effects cannot be ignored. The elevated HQ values for lead and cadmium are particularly concerning given their well-documented toxicological impacts, including neurological damage and kidney dysfunction (Tchounwou et al., 2021; WHO, 2022). These findings are consistent with previous studies that reported high health risk indices in industrial and peri-urban environments (Egbueri & Unigwe, 2020; Rahman et al., 2021). The results highlight the urgent need for intervention measures, including water treatment, pollution control, and public health awareness programs.

The results of this study provide strong empirical evidence that groundwater in peri-urban communities of Lagos and Ogun States is significantly impacted by heavy metal contamination, driven primarily by anthropogenic activities. The combination of descriptive, correlation, and regression analyses confirms that industrial activities, waste disposal practices, and agricultural inputs are key determinants of contamination patterns. The spatial variability observed in the data underscores the importance of geospatial analysis in identifying contamination hotspots and guiding targeted interventions. Furthermore, the health risk assessment reveals that a significant proportion of the population is exposed to unsafe levels of heavy metals, posing serious long-term health risks. In conclusion, the findings align with global and regional studies on groundwater contamination, while also contributing new insights through the integration of geospatial and statistical approaches. The study therefore provides a robust empirical basis for policy formulation, environmental regulation, and sustainable groundwater management in peri-urban Nigeria.

5. Conclusion and Recommendations

This study provides a comprehensive empirical assessment of groundwater quality and heavy metal contamination in peri-urban communities of Lagos and Ogun States using an integrated approach that combines hydrochemical analysis, geospatial techniques, and advanced statistical modelling. The findings reveal that groundwater in the study area is significantly contaminated with toxic heavy metals, particularly lead (Pb), cadmium (Cd), and arsenic (As), with mean concentrations exceeding World Health Organization permissible limits in several locations. The observed spatial variability in contamination levels highlights the influence of localized anthropogenic activities, especially industrial operations, indiscriminate waste disposal, and agricultural practices. The regression and correlation analyses further confirm that groundwater contamination is largely driven by proximity to industrial zones, waste disposal sites, and agricultural runoff, indicating a multi-source pollution pattern. The strong explanatory power of the model underscores the robustness of these determinants in predicting contamination levels. In addition, the health risk assessment indicates that a significant proportion of the population is exposed to non-carcinogenic risks, particularly from lead and cadmium, with Hazard Quotient values exceeding safe thresholds. This suggests that continued consumption of untreated groundwater in these communities poses serious public health concerns.

Based on the findings of this study, the following recommendations are proposed:

1. Regulatory agencies should enforce stricter controls on industrial effluent discharge and ensure compliance with environmental standards. Regular monitoring and penalties for non-compliance should be implemented to reduce heavy metal pollution.
2. Government and relevant stakeholders should institutionalize continuous groundwater quality monitoring using GIS-based systems to track contamination trends, identify hotspots, and support data-driven decision-making.
3. Affordable and locally adaptable water treatment technologies, such as filtration systems and adsorption methods, should be introduced to reduce heavy metal concentrations in drinking water at the household level.
4. Proper waste disposal systems, including engineered landfills and recycling programs, should be developed to minimize leachate infiltration into groundwater systems, particularly in peri-urban areas.
5. Awareness campaigns should be conducted to educate communities on the risks associated with contaminated groundwater and promote safe water practices, including boiling, filtration, and periodic water testing.
6. Urban planning policies should incorporate groundwater protection measures, including zoning regulations that restrict industrial activities near residential and water supply areas.
7. Farmers should be encouraged to adopt environmentally friendly practices, including controlled use of fertilizers and pesticides, to reduce contamination from agricultural runoff.
8. A centralized and accessible database should be developed to store groundwater quality data across regions, facilitating research, policy formulation, and inter-agency collaboration.

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