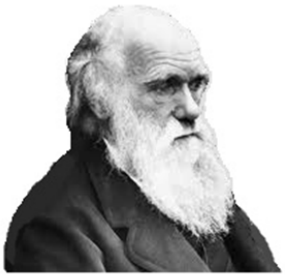
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Deforestation, Land use Change and Groundwater Quality in Peri-Urban of Ibadan Zone, Southwestern Nigeria: A case Study of Ido Local Government Area

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ABSTRACT

Deforestation and changes in land use and land cover (LULC) can significantly affect groundwater quality in peri-urban areas. However, the relationships between vegetation loss, groundwater quality remain insufficiently documented in southwestern Nigeria. This study examined LULC changes and their implications groundwater quality in the Ido Local Government Area (LGA), Ibadan, Southwestern Nigeria. Multi-temporal Landsat imagery covering 2005-2025 and the Normalized Difference Vegetation Index (NDVI) were used to analyze changes in vegetation and land cover. Forty groundwater samples were collected from four land-use types: built-up areas, sparse vegetation, shrubs/grassland, and dense vegetation, with ten samples from each land-use types. Physicochemical parameters and heavy metals were analysed using standard methods. Descriptive statistics, One-way analysis of variance (ANOVA), Tukey's HSD tests, Heavy Metal Pollution Index

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(HPI), and Heavy Metal Evaluation Index (HEI) were employed to evaluate different in groundwater quality across the land-use types. Results indicated a significant decrease in dense vegetation cover, dropping from 57.47% in 2005 to 4.74% in 2025, representing a reduction of about 91.8% while built-up areas lingering from 4.44% to 23.60%. Groundwater in built-up areas showed highest nitrate concentrations (17.19 ± 0.70 mg/L), electrical conductivity (473.87± 9.05 µS/cm), lead (0.02 mg/L) and cadmium (0.003) while those from densely vegetated areas recorded lower nitrate and lead concentrations of 0.003 mg/L and 0.002 mg/L respectively. Statistical analysis indicated significant differences ($p < 0.05$) among land-use types. HPI values range from 53.77 in densely vegetated areas to 115.57 in built-up zones, while HEI values rise from 1.56 to 5.08, indicating low to high contamination. This study highlights the relationship vegetation loss, urbanization and deteriorating groundwater quality. Forest restoration, regular groundwater monitoring and sustainable land-use planning are recommended for protection of groundwater resources.

***Keywords*:** Deforestation, Groundwater quality, Heavy metal contamination, Land use/land cover change, Urbanization

1. INTRODUCTION

Groundwater plays a crucial role in providing water for domestic, agricultural, and socioeconomic needs in sub-Saharan Africa, especially in rural and peri-urban areas where access to reliable piped water is limited. In southwestern Nigeria, the presence of groundwater is primarily influenced by weathered and fractured basement rocks, with the productivity of aquifers being affected by factors such as the depth of weathering, the extent of fractures, and the conditions for recharge (Bianchi et al., 2023). Thus, the sustainability of groundwater resources is closely tied to geological and climatic factors, as well as land-use practices that can impact both recharge rates and contamination risks.

Changes in land use and land cover (LULC), including deforestation, can significantly affect processes like rainfall interception, evapotranspiration, soil structure, infiltration, and surface runoff. The transformation of natural vegetation into agricultural land, urban areas, and infrastructure can either enhance or diminish groundwater recharge, depending on the specific local conditions. For instance, soil compaction and the creation of impervious surfaces can hinder infiltration, while the removal of vegetation may lead to a decrease in evapotranspiration. These varying impacts underscore the importance of evaluating land-cover changes within particular geological and environmental contexts (Barua et al., 2021).

Moreover, alterations in land use can influence groundwater quality by changing the sources of pollution and the pathways through which contaminants travel. Agricultural practices may introduce nutrients and agrochemicals into the environment, while poor sanitation, improper solid-waste disposal, and wastewater discharge can heighten contamination risks. The chemistry of groundwater in southwestern Nigeria illustrates the complex interactions between geological conditions and human activities (Tijani et al., 2014), and addressing groundwater pollution remains a significant management challenge throughout Africa (Ouedraogo & Vanclooster, 2021).

Studies in Ibadan have examined groundwater quality across different land-use types and the effects of LULC changes on water quality in the Eleyele catchment (Ayeni, 2024; Ogundairo et al., 2025). However, results from other areas might not accurately reflect the situation in Ido Local Government Area (LGA), where factors like geology, historical land use,

settlement patterns, and sources of pollution can vary significantly. Therefore, there is need to understand the relationship between land cover patterns and groundwater quality.

This study focuses on analyzing LULC changes in Ido LGA from 2005 to 2025 and explores their spatial relationship with groundwater quality. It specifically looks at change in land-cover types, assesses the physicochemical properties and heavy-metal concentrations in groundwater, and compares water quality across different land-use types. By integrating remotely sensed imagery with groundwater analysis, the research aims to provide valuable insights that can aid in vegetation conservation, sustainable land-use planning, and effective groundwater management in Ido LGA and similar peri-urban areas.

2. MATERIALS AND METHODS

2. 1. Study area

Ido LGA is situated in the western part of Ibadan, within Oyo State, Nigeria, covering an area of about 870 km^2. It is bordered by Akinyele, Ibadan North, Ibadan Southwest, and Ona-Ara LGAs. The region has a humid tropical climate, with average annual rainfall between 1200 and 1500 mm, mostly falling from April to October. The geology is mainly characterized by a crystalline basement complex, which has fractured aquifers at shallow depths, making the groundwater supply highly reliant on local recharge. Key land uses in Ido include agriculture, forestry, residential developments, and light industry.

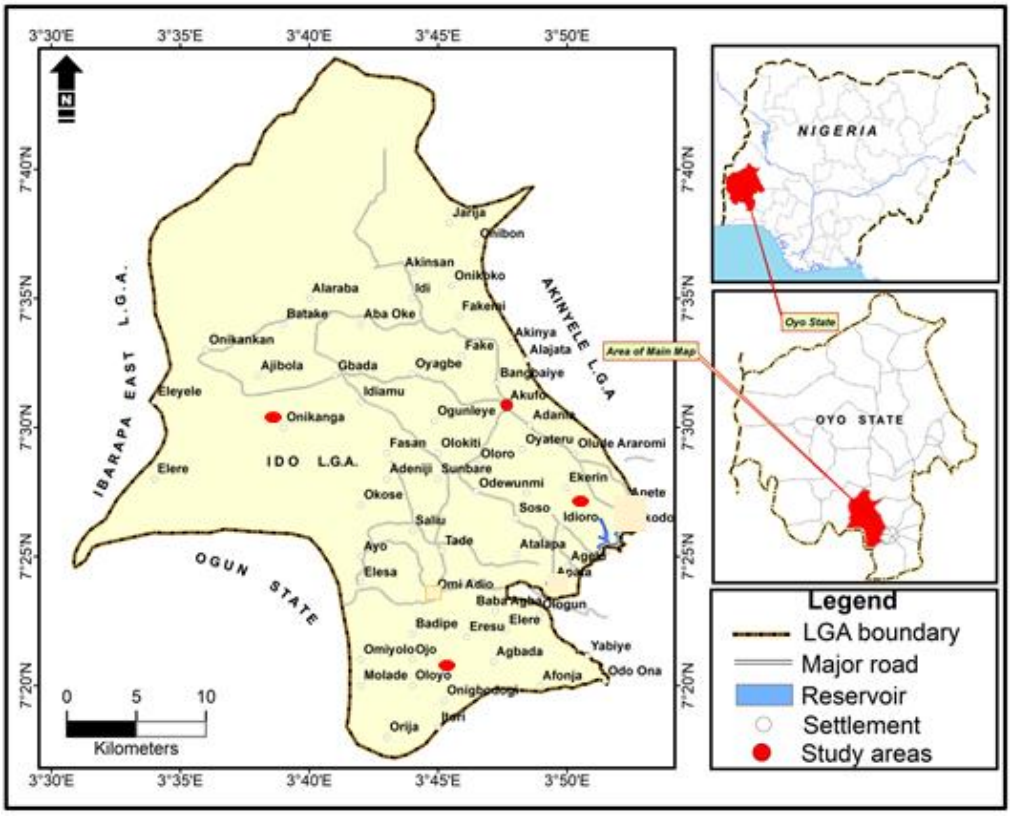


Figure 1. Location map of the Study Area.

2. 2. Land-Use /Land-Cover Classifications

Landsat imagery from multiple years (2005, 2015, and 2025) was gathered and processed to correct for atmospheric effects. The NDVI was calculated to assess vegetation density, and a supervised maximum-likelihood classification was used to identify four land use and land cover (LULC) categories: built-up areas, dense vegetation, shrubs/grasslands, and sparse vegetation. The accuracy assessment showed an overall accuracy of over 85% and Kappa coefficients exceeding 0.80. The percentage of area covered by each class was determined for each time period.

2. 3. Sampling

Four groundwater sampling sites were carefully chosen based on the LULC map to reflect different land-use types (Figure 1). Idi Oro (Built-up) is a highly urbanized area with many impervious surfaces and little vegetation; Akufo (Sparse Vegetation) represents a rural setting with mixed agriculture, featuring patchy grasses and shrubs; Onikanga (Shrubs/Grasslands) serves as a transitional ecological zone with a moderate density of vegetation, while Oloyo (Dense Vegetation) is noted for its thick plant cover and minimal human interference. A total of forty groundwater samples (10 from each area) were collected randomly at each site. The sampling containers were pre-washed using dilute HNO_3 and rinsed with deionized water. At each location, the bottles were rinsed with groundwater prior to the final collection, and water was drawn for several minutes to ensure stagnant water was displaced. Approximately 1.5 liters were collected from each site; subsamples intended for cation and trace-metal analysis were acidified to a pH of less than 2 using dilute HNO_3, while the anion subsamples remained unacidified. All samples were kept in an ice chest for transport to the laboratory

2. 4. Physiochemical Analysis

At each sampling point, depth to water table was measured. In-situ measurements were taken using a Hach HQ40D portable multi-parameter meter to determine pH, electrical conductivity (EC, µS/cm), and total dissolved solids (TDS, mg/L). For the laboratory analyses, we analyzed major cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) and anions (HCO_2^{-}, Cl^{-}, SO_4^{2-}, NO_3^{-}) according to the standard methods set by APHA (2017).

2. 5. Heavy metal analysis

Heavy metals such as Pb, Cd, Cr, Ni, Zn, Cu, Fe, and Mn were analyzed using Atomic Absorption Spectrophotometry (AAS) in accordance with the standard methods outlined by APHA (2017). Calibration standards were created for each metal, and quality control measures were implemented using certified reference materials and duplicate samples. The detection limits were established at 0.001 mg/L for Pb, Cd, Cr, and Ni; 0.005 mg/L for Zn and Cu; and 0.01 mg/L for Fe and Mn.

2. 6. Heavy Metal Pollution Indices

The Heavy Metal Pollution Index (HPI) was determined using the weighted arithmetic quality mean method, as outlined in Equation 1 by Mohan et al. (1996).

$$HPI = \frac{\sum_{i=1}^{n} = \mathrm{WiQi}}{\sum_{i=1}^{n} \mathrm{Wi}} \qquad Equation\ 1$$

where: *Wi* is the unit weight of the i*th* parameter, *Qi* is the sub-index of the i*th* parameter, and *n* is the number of parameters.

The Heavy Metal Evaluation Index (HEI) was determined using the formula provided by Edet and Offiong (2002) as shown in Equation 2:

$$HEI = \sum_{i=1}^{n} \frac{\mathrm{Ci}}{\mathrm{M\ ACi}} \qquad Equation\ 2$$

where: C_i is the observed concentration and M AC_i is maximum admissible concentration

2. 7. Statistical Analysis

Descriptive statistics, including the mean and standard deviation, were calculated for all parameters. To assess significant differences among land-use classes, one-way ANOVA was employed, followed by Tukey HSD post-hoc tests for pairwise comparisons. A significance level of $p < 0.05$ was established. All analyses were conducted using SPSS version 20 and R version 4.3.

3. RESULTS AND DISCUSSION

3. 1 Land-Use/Land-Cover Dynamics (2005–2025)

The NDVI-based classification highlighted significant changes in land cover within Ido LGA from 2005 to 2025 (see Figure 2 and Table 1). Dense vegetation saw a steep decline, dropping from 57.47% in 2005 to 10.21% in 2015, and further down to 4.74% by 2025, marking a staggering 91.8% decrease over the two decades. In contrast, built-up areas grew from 4.44% to 22.68% and then to 23.60% across the same years. Additionally, shrubs and grasslands rose from 15.30% to 37.91%, while sparse vegetation reached its highest point at 55.87% in 2015 before falling to 33.81% in 2025. These trends reflect rapid deforestation, urban expansion, and advancements in agriculture.

Table 1. Land Use Classification of Ido LGA (2005–2025).

Land Use Class	2005 Area (%)	2015 Area (%)	2025 Area (%)
Built-up areas	4.44	22.68	23.60
Dense vegetation	57.47	10.21	4.74
Shrubs/Grasslands	15.30	11.24	37.91
Sparse vegetation	22.81	55.87	33.81

The results reveal a significant change in land cover within the Ido Local Government Area (LGA) from 2005 to 2025. Dense vegetation has decreased dramatically from 57.47% to 4.74%, marking a reduction of about 91.8%. In contrast, built-up areas have risen from 4.44% to 23.60%.

This trend highlights a substantial transition from green spaces to developed land. Similar transformations have been observed in southwestern Nigeria, where the loss of forests and the growth of agricultural and urban areas have reshaped the environment (Fasona et al., 2022; Olayungbo, 2021).

However, the impact of these changes can vary based on local soil types, geological features, and drainage systems (Oswald et al., 2023).

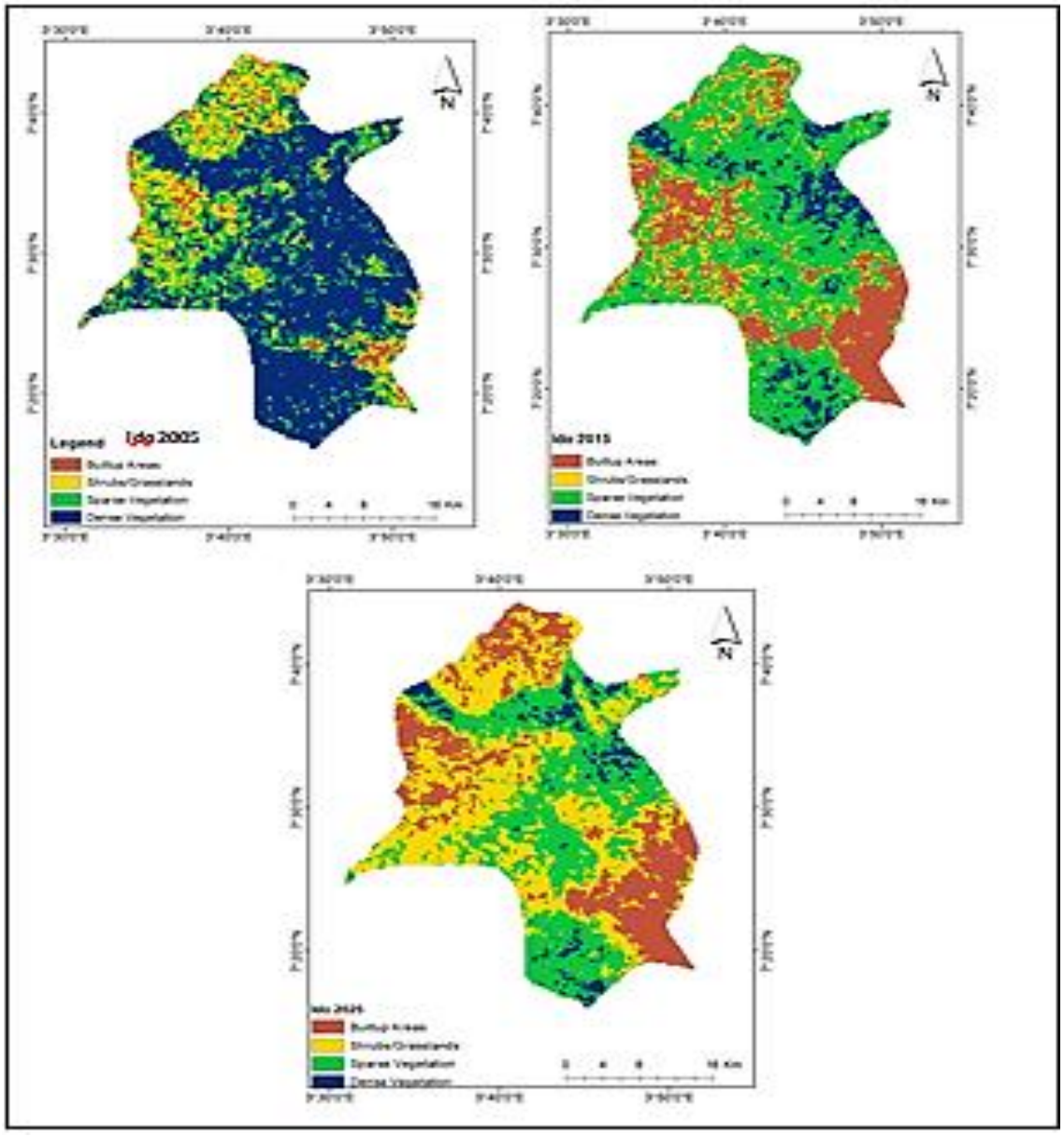


Figure 2. Land use Land cover for 2005, 2015 and 2025 in Ido LGA.

Groundwater data also revealed that the average depth to water in built-up areas is greater (12.54 m) compared to densely vegetated regions (8.56 m) (Table 2). This discrepancy points to differences in groundwater conditions among various land-use types. Nonetheless, it does not conclusively prove that urban growth has directly diminished groundwater recharge, as other factors like topography, aquifer properties, well construction, and groundwater extraction can also affect water levels. These results underscore the need to consider land-cover changes in conjunction with local hydrogeological factors when evaluating groundwater resources in rapidly evolving peri-urban areas.

3. 2. Physiochemical parameters of groundwater samples

The comprehensive descriptive statistics (mean ± standard deviation) for all measured physiochemical parameters of the water samples across different land-use types along with Tukey HSD post-Hoc are presented in Table 2.

Table 2. Mean Values of Physiochemical Parameters of Ground water across land use types.

Parameters	**Land use class**				**WHO (2022)**
	Built-up	Sparse vegetation	Shrub/grassland	Dense Vegetation	
Well Depth	12.54 ±0.94	11.13 ±0.65	10.09 ±0.33	8.56 ±0.67	
pH	6.25 ±0.14	6.54 ±0.09	6.63 ±0.05	6.73 ±0.09	6.5-8.5
EC (µS/cm)	473.87 ±9.05	349.77 ±3.15	309.39 ±2.30	211.23 ±1.96	
TDS (mg/l)	302.97 ±5.83	226.16 ±10.35	192.93 ±4.23	136.12 ±0.81	
NO_3^- (mg/l)	17.19 ±0.70	11.52 ±0.77	8.42 ±0.49	2.78 ±0.07	50
SO_4^{2-}	44.70 ±0.621	28.07 ±0.78	15.21 ±4.75	10.16 ±0.49	250
HCO_3^-	148.56 ±3.38	125.95 ±0.83	101.53 ±0.70	84.83 ±0.51	-
Cl^-	37.90 ±1.74	25.16 ±0.80	18.35 ±0.45	10.56 ±0.39	250
Na^+	44.03 ±3.14	29.97 ±1.02	19.94 ±1.10	11.29 ±0.57	200
K^+	9.09 ±0.55	6.06 ±0.46	5.52 ±0.42	3.38 ±0.69	12
Ca^{2+}	66.07 ±1.96	54.66 ±2.01	44.74 ±1.77	30.99 ±0.69	75
Mg^{2+}	37.71 ±1.96	29.96 ±1.04	22.07 ±0.95	15.10 ±0.49	50

Notes: Values with the same letter within a row are not significantly different at $p>0.05$.

Values with the same letter (a, b, c, d) within a row are not significantly different at p>0.5. The results reveal a strong and statistically significant environmental trend. Areas with dense

vegetation exhibited the highest pH level at 6.74 ± 0.09, the lowest electrical conductivity (EC) at 211.23 ± 1.96 µS/cm, the lowest total dissolved solids (TDS) at 136.12 ± 0.81 mg/L, the lowest nitrate concentration at 2.78 ± 0.07 mg/L, and the shallowest water tables at 8.56 ± 0.67m. In contrast, built-up areas had the lowest pH of 6.25 ± 0.14, highest EC (473.87± 9.05 µS/cm), TDS (302.97± 5.83 mg/L), nitrate (17.19 ± 0.70 mg/L) and deepest water tables of 12.54 ± 0.94m while shrubs/grasslands and sparse vegetation values that fell in between these.

Similarly, built-up areas showed the highest average concentrations of calcium (66.07 ± 1.96 mg/L), magnesium (37.71 ± 1.96 mg/L), sodium (44.03 ± 4.14 mg/L), potassium (9.09 ± 0.55 mg/L), bicarbonate (148.56 ± 3.38 mg/L), chloride (37.90 ± 1.74 mg/L) and sulphate (148.56 ± 3.38 mg/L) while dense-vegetation areas typically showed the lowest levels. This trend indicates that groundwater chemistry is influenced by land-use practices. A similar observation was made by Ayeni (2024) in Ibadan, where residential zones had higher concentrations of various physicochemical parameters compared to agricultural and industrial regions. These variations may stem from both natural interactions between water and rock and human activities. The elevated levels of nitrate and chloride in built-up areas could be linked to domestic wastewater, leaking septic systems, and inadequate waste management. Katz et al. (2011) noted that nitrate, chloride, sodium, and other dissolved substances serve as valuable indicators when assessing the potential effects of septic-system effluent on groundwater. Abascal et al. (2022) also highlighted sewage, septic tanks, landfills, and agricultural practices as significant contributors to groundwater nitrate contamination. However, the concentrations observed alone cannot definitively identify a specific pollution source; further evidence, such as sanitary surveys, microbial analyses, or chemical-source indicators, would be necessary to determine the origin of these constituents.

The average nitrate concentration in urban areas was found to be 17.19 mg/L, which is well below the World Health Organization's guideline limit of 50 mg/L for nitrate (WHO, 2022). Similarly, the respective mean chloride and sulphate concentrations of 37.90 mg/L) and 148.56 were both below the levels that can typically raise taste-related issues. The mean pH level of 6.25 in urban areas is slightly lower than the recommended range of 6.5–8.5, which may reflect acidification from organic matter decomposition and atmospheric deposition (Akintola *et al.,* 2021).

On the other hand, groundwater in areas with dense vegetation showed nitrate levels below 3 mg/L and electrical conductivity below 250 µS/cm, indicating lower concentrations of dissolved ions in the areas compared to urban settings. However, having low nitrate and electrical conductivity does not necessarily mean that forest vegetation effectively filters out contaminants or ensures safe groundwater. The intermediate levels found in shrub/grassland and sparse-vegetation areas indicate a variation in groundwater chemistry across different land-use types. Since this study was based on a single sampling event, these variations should be viewed as spatial correlations rather than definitive evidence that the loss of vegetation has led to groundwater quality decline.

3. 3. Heavy metal Concentrations across Land use Types

Table 3 indicates that built-up areas exhibited the highest average concentrations of Pb (0.021 ± 0.002 mg/L), Cd (0.007 ± 0.001 mg/L), Cr (0.013 ± 0.002 mg/L), and Ni (0.019 ± 0.001 mg/L). In contrast, areas with dense vegetation showed respective lowest concentrations of Pb, Cd, Cr and Ni as follows: 0.003 ± 0.001, 0.002 ± 0.001, 0.006 ± 0.003, and 0.007 ± 0.004 in mg/L. Additionally, Zn, Cu, Fe, and Mn levels were also highest in built-up areas, yet they

remained within the acceptable limits set by WHO (2022) guidelines. The increased levels of Pb and Cd in urban areas may be linked to waste disposal, wastewater infiltration (Akintola et al, 2021), or other urban activities, although these sources cannot be definitively identified based solely on concentration levels

Table 3. Mean Concentration values of Determined Heavy Metals in Groundwater Samples.

Parameters (mg/L)	Land use class				WHO (2022)
	Built-up	Sparse vegetation	Shrub/grassland	Dense vegetation	
Pb	0.021 ± 0.002	0.012± 0.001	0.009 ± 0.001	0.003 ± 0.001	0.01
Cu	0.036 ± 0.004	0.022 ± 0.005	0.014 ± 0.002	0.007 ± 0.001	50
Zn	0.061 ± 0.006	0.041 ± 0.009	0.027 ± 0.002	0.012 ± 0.002	2
Cr	0.013 ± 0.002	0.007 ± 0.002	0.006 ± 0.001	0.006 ± 0.003	0.05
Ni	0.019 ± 0.001	0.011 ± 0.001	0.007 ± 0.004	0.007 ± 0.004	0.02
Fe	0.198 ± 0.009	0.116 ± 0.023	0.078 ± 0.009	0.031 ± 0.021	200
Cd	0.003 ± 0.001	0.003 ± 0.001b	0.002 ± 0.001	0.002 ± 0.001	0.3
Mn	0.068 ± 0.004	0.041 ± 0.00	0.004 ± 0.003	0.004 ± 0.003	0.4

Notes: Values with the same letter within a row are not significantly different at $p>0.05$

A comparison with WHO (2022) guidelines reveals that the average Pb (0.021 mg/L) concentrations surpassed the e guideline values of 0.01 mg/L. Conversely, Cr and Ni concentrations stayed below their guideline thresholds of 0.05 and 0.02 mg/L. These results underscore the necessity for ongoing monitoring and further investigation into potential sources of contamination. The observed differences suggest a spatial relationship between land use and metal concentrations, but they do not confirm that the loss of vegetation directly caused groundwater contamination.

3. 4. Heavy Metal Pollution Indices

Table 4 shows that both the Heavy Metal Pollution Index (HPI) and the Heavy Metal Evaluation Index (HEI) show an upward trend from areas with dense vegetation to urbanized regions. Specifically, HPI values range from 53.77 in densely vegetated areas to 115.57 in built-up zones, while HEI values rise from 1.56 to 5.08. Areas with dense vegetation are categorized as having low contamination (HEI = 1.56), low to moderate contamination in shrub and grassland areas (2.38), moderate in sparse vegetation (3.41), and very high contamination in urban areas (5.08), based on the classification of Mohan et al (1996). The elevated index values in urban areas suggest a higher cumulative heavy-metal burden, likely due to increased exposure to urban pollution sources such as wastewater infiltration and inadequate waste management. Previous studies utilizing heavy-metal indices have proven effective in

comparing groundwater metal contamination across different locations (Boateng et al., 2015; Triassi et al., 2023). Nevertheless, it is crucial to recognize that these indices aggregate measured concentrations relative to established standards and do not serve to pinpoint contamination sources or evaluate potential health implications. The identified pattern reveals an association between land-use classification and heavy-metal pollution, emphasizing the importance of sustained groundwater surveillance and comprehensive examination of possible contamination pathways.

Table 4. Heavy metal Pollution Index (HPI) and Evaluation Index (HEI).

Land use	HPI		HEI	
	Values	Status at Threshold of 100	Values	Pollution status
Dense Vegetation	53.77	Safe	1.56	Low
Shrubs/Grasslands	65.60	Safe	2.38	Low to Moderate
Sparse Vegetation	95.33	Approaching Critical Limit	3.41	Moderate
Built up	115.57	Unsafe	5.08	High Contamination

4. CONCLUSIONS

This study revealed significant differences in groundwater quality among different land-use types in the Ido Local Government Area of Ibadan, located in southwestern Nigeria. The reduction in dense vegetation and the growth of urban areas from 2005 to 2025 were linked to variations in groundwater physicochemical properties and heavy metal levels. Results from ANOVA and Tukey HSD showed that urban areas typically had higher concentrations of electrical conductivity, nitrate, sodium, lead, and cadmium, whereas areas with dense vegetation tended to have lower levels.

These results underscore the significance of land-use patterns in assessing groundwater quality. The study suggests the need for vegetation conservation, enhanced sanitation and waste management practices, and ongoing groundwater monitoring, especially in areas experiencing rapid urbanization. However, since groundwater samples were taken during just one campaign, additional seasonal monitoring and source evaluations are essential to identify temporal trends and better understand the processes behind the observed variations.

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