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Contrasting Hydrogeochemical Profiles: A Comparative Analysis of Industrial, Agricultural and Residential Zones in Lagos State, Nigeria

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Abstract

This study provides a comparative analysis of groundwater quality between industrial, agricultural and residential zones in Lagos State, Nigeria. Using 25 groundwater samples, the research assessed physicochemical parameters and concentrations of heavy metals, including lead (Pb), zinc (Zn), chromium (Cr), nickel (Ni), and copper (Cu). All physicochemical parameters indicates high acidity level of sampled water with pH (5.13±0.46 - 6.31±0.15). EC, D.O., Nitrate, Phosphate, TDS, Sulphate and Phosphate were all within the WHO regulatory limits. The results of analyzed groundwater from the Agricultural lands revealed heavy metal contamination of Lead (0.22±0.21mg/l) and Nickel (0.03±0.02mg/l). This is resultant from the associated impact of agricultural and industrial activities within the study area These findings underscore the need for effective water management policies and targeted interventions to prevent groundwater contamination.

Keywords: *Heavy metals, contamination, groundwater, hydrogeochemical*

Introduction

Groundwater is essential for domestic and industrial use in Lagos, yet it is increasingly threatened by contamination from agricultural and urban activities. Seasonal variations, including limited recharge during the dry season and heavy rainfall during the wet season, significantly affect water chemistry (Adeoti & Oyewumi, 2020). Water beneath the ground is an important natural resource globally, particularly where there is little or no water on the surface. In Lagos, Nigeria groundwater supports a wide range of activities such as domestic uses, agriculture and industrial operations. Its sustainability in Lagos is, however, undermined by over-abstraction, pollution and changing land uses, among others. Groundwater serves as a pillar for Lagos City, which is a megacity characterised by an increasing population and growing economic activities. For many people living in areas not served by public water supply systems, groundwater serves them right as their main source of drinking water. It also helps in agriculture through irrigation, which enhances crop production, ensuring food security within communities. Groundwater is also useful to diverse

industrial purposes ranging from manufacturing processes to cooling down heat used during cleaning (Olabode & Comte, 2022).
Rapid urbanization, industrial expansion and intensive agricultural practices significantly influence groundwater hydrogeochemistry, which leads to water quality deterioration and increased cost of extraction (Faremi & Oloyede, 2010).

There are growing concerns regarding the sustainability of groundwater resources in Lagos state. Over-exploitation results in falling water tables and possible aquifer depletion due to regions where extraction rates exceed natural recharge rates occur, leading to a decline in yield (Olaniran et al., 2016). Furthermore, agricultural runoff, urban waste discharges and mainly industrial effluents cause pollution that finds its way underground through infiltration, degrading the quality of this vital resource (Wright et al., 2005). Various forms of land utilization, like urbanization coupled with intensive farming practices, compound these challenges, thereby interfering with the normal hydrological cycle and affecting contamination risks.

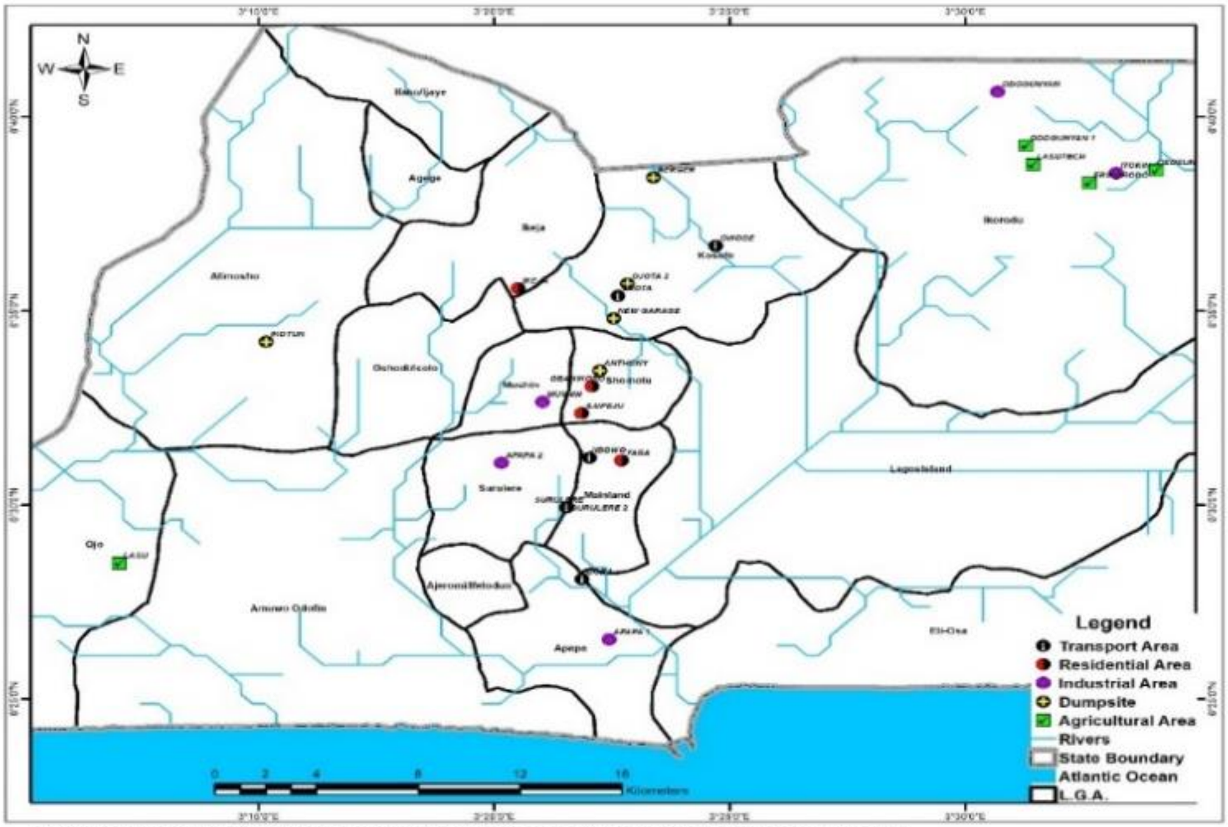
Previous studies have established the role of land use in influencing groundwater quality (Omoyeni & Iwuoha, 2020). Industrial zones often exhibit elevated levels of metals, such as lead and zinc, while residential areas tend to experience lower contamination levels. However, limited studies compare these zones quantitatively.

This study investigates the hydrogeochemical differences between industrial, agricultural and residential zones, focusing on how human activities impact groundwater quality and exploring whether these differences are significant.

Materials and Methods

Study Area

Lagos is located in southwestern Nigeria, characterized by tropical wet and dry seasons (Egbinola & Amanambu, 2019). The study area covers diverse land-use zones, including urban centers, agricultural lands, and industrial areas, each contributing uniquely to groundwater contamination.



MAP SHOWING SAMPLING LOCATIONS ACROSS DIFFERENT LAND-USE TYPES IN THE STUDY AREA

Figure **3.1: Map showing sampling locations across different land-use types in the study area**

Sample collection

Standard methods were followed in order to guarantee the reproducibility and reliability of results (APHA, 2005). Sampling sites were selected to represent different land uses such as residential, industrial and agricultural-use areas. Water samples were collected from boreholes or wells at different depths in order to capture vertical variations in groundwater quality (APHA, 2005, Abd Elnabi et al, 2023).

Twenty-five groundwater samples were collected from industrial, agricultural and residential zones across Lagos. Physicochemical parameters, including pH, electrical conductivity, and temperature, were measured *in situ*. Heavy metal concentrations were analysed using inductively coupled plasma mass spectrometry (ICP-MS). One-way ANOVA was used to assess whether differences in contaminant levels between the zones were statistically significant.

Statistical analysis was conducted using Microsoft Excel, SPSS, and R-Studio. Principal component analysis (PCA) was used to identify correlations between metal concentrations and land-use patterns.

Results

Physicochemical Parameters Across Zones

The physicochemical properties of groundwater provide insights into its overall quality, highlighting the influence of different land-use activities. Table 1 summarizes the results of the in-situ measurements.

pH:
The pH levels in the Agricultural zone (5.13 ± 0.46) were significantly lower than in the residential zone (6.21 ± 0.18) and Industrial zone (6.31±0.15). This suggests more acidic conditions in the Agricultural areas than in Residential and industrial areas, likely due to the discharge of agricultural effluents, which often contain acids and other reactive chemicals. In the present study, the mean pH shows that the pH of most of the groundwater across the study area is acidic. These are, however, higher than the range of 3.19-5.18 reported by (Adetoyinbo et al., 2010) in Uyo, Nigeria. The pH values obtained across the study area are slightly below the recommended WHO standard of 6.50 to 8.50 (WHO, 2006).

Electrical Conductivity:
Electrical conductivity (EC), which measures the concentration of dissolved ions in water, was notably higher in the Agricultural area (248.01±85.22 µS/cm) compared to the industrial zone (102.38 ± 11.46 µS/cm) and residential zone (114.28 ± 14.11 µS/cm). The elevated EC in the industrial zone suggests a higher ionic load, possibly from industrial discharges, including salts and metal ions.
The conductivity of a medium indicates the ability to conduct an electric current. It is assessed by the existence of the total concentration of ions, temperature, etc. The electrical conductivity, across the study areas and land uses, were all within the WHO permissible limit or conductivity in groundwater (WHO, 2006). All land uses show EC values well below the WHO limit, indicating acceptable levels of ionic concentration in the water (Selvakumar et al., 2017). However, the agricultural use area show higher variability and mean EC values, which may be due to leachates and fertilizers.

Salinity:
The residential and industrial zones exhibited higher salinity (0.06 ± 0.01 ppt) and (0.06 ± 0.01ppt) than the agricultural zone (0.01 ± 0.00ppt). This difference could be attributed to the use of chemicals and salts in industrial processes, which are subsequently discharged into the environment.

Temperature:
The highest mean temperature (26.28±0.11^{0}C) was recorded in Industrial lands, while the lowest was recorded in Agricultural lands (26.06±0.31^{0}C). The mean temperature range of the study area is within the range of 25-30^{0}C for groundwater stipulated by WHO, indicating no significant thermal pollution (Tania et al., 2021). The temperature values for all land uses are consistent with the values of 26.5 to 27.5°C reported by Akinbile et al. (2016) from Akure Ondo State, Nigeria, and 26.3^{0}C to 28.3^{0}C reported by Adetoyinbo et al., in Uyo, Akwa Ibom State.

The concentration of Dissolved Oxygen (DO) in groundwaters depends on the physical, chemical and biochemical activities in the water. DO values (8.00±0.27mg/l -8.77±0.10mg/l) obtained in this study varied from the WHO permissible limit of 5.0mg/l; however, it is higher than the 3.9±0.4mg/l to 4.7±0.46 reported by Oko et al. (2017).

The concentration of Nitrate in this study which ranged between 1.93±0.30mg/l to 3.71±0.72mg/l was lowest in the residential area. These were below the limits set by WHO, which is 50mg/L. Lower ranges of (6.6 - 9.68mg/L) were reported by Wizor and Nwankwo (2019) from Woji Creek in Rivers State. But higher than the 0.185mg/l reported by (Akiwumi et al., 2012) in Ilorin. The results were slightly uniform across stations. The nitrate concentrations from the study were also lower than those of Adejuwon and Mbuk (2011), who recorded a higher nitrate concentration of 50.6 mg/l in well water in Ikorodu. The low variation recorded for nitrate concentration in this study may be due to differences in hydro-geological regimes (Akankali *et al*, 2022). Generally, lifetime exposure to nitrite and nitrate at levels above the maximum acceptable concentration could cause such problems as diuresis, increased starch deposits and haemorrhaging of the spleen (Reimann *et al*., 2003).

The values of phosphate 1.00±0.06mg/l in residential area to 2.07±0.23mg/l in industrial area observed in this study are within the WHO permissible limit of 12mg/l. A lower range of 0.07-0.13 had been reported by (Oyem et al., 2017) in some Ika communities in Delta State. The Phosphate content was lowest in the residential areas and highest in the industrial areas. Phosphate is a major fertilizer constituent, it can cause severe digestive complications from chronic exposures.

The mean Chloride concentrations in groundwater across the various land uses showed that Chloride was within the WHO permissible limit of 250mg/l in the Agricultural, Industrial, Residential and Transportation lands, but exceeded the WHO regulatory limit in the dumpsites. The results obtained in this study which ranged between 95.74±15.51mg/l in Agricultural area to 161.49±35.75mg/l in industrial area are however in higher than the range of 2.40mg/l - 1730.00mg/l reported by Ishaku, (2011) in Northeastern, Nigeria, and the 6.01-mg/l – 31.05mg/l by (Amangabara & Ejenma, 2012) in Bayelsa, Nigeria.

The mean concentration of HCO_3 which ranged between 140.33±19.82mg/l in Agricultural area to 170.08±13.77mg/l were below the WHO regulatory limit of 1000mg/l. A similar range of 19.50 - 563.60mg/l was reported by (Ishaku, 2011) in Northeastern Nigeria., but higher than the 24.0mg/l – 41.02mg/l reported by Amangabara and Ejenma, (2012) in Bayelsa environs, Nigeria.

Table 1: Results of Physicochemical Parameters Across study area

Parameters	Agricultural land use	Industrial land use	Residential land use	p-value	WHO-limit
pH	5.13±0.46	6.31±0.15	6.21±0.18	0.00	6.5-8.5
EC (µS/cm)	248.01±85.22	102.38±11.46	114.28±14.11	0.002	1000
Salinity (ppt)	0.01±0.00	0.05±0.01	0.06±0.01	0.021	
TDS (mg/l)	115.83±39.91	42.25±4.55	47.25±6.21	0.001	500
Temp (^{0}C)	26.06±0.31	26.28±0.11	26.18±0.11	0.764	25-32
Dissolved Oxygen	8.00±0.27	8.31±0.18	8.77±0.10	0.038	5.0
Chloride (Cl_2)	95.74±15.51	161.49±35.75	139.89±6.90	0.030	250
Nitrate (NO_2)	3.68±0.51	3.71±0.72	1.93±0.30	0.021	50
Phosphate (PO_4)	1.27±0.10	2.07±0.23	1.00±0.06	0.000	12
Sulphate (SO_2)	15.53±9.24	60.52±18.01	35.66±7.04	0.044	200
HCO_3	140.33±19.82	170.08±13.77	165.05±2.19	0.403	1000

Table 2: Heavy Metal Concentrations Across Zones

Metals	Agricultural zone	Industrial zone	Residential zone	p-value	WHO-limit
Cr (mg/l)	0.04±0.02	0.03±0.01	0.00±0.00	0.000	0.05
Cu (mg/l)	0.03±0.02	0.17±0.05	0.02±0.01	0.000	1.0
Ni (mg/l)	0.03±0.02	0.02±0.01	0.01±0.00	0.007	0.02
Zn (mg/l)	0.19± 0.03	28.79±15.53	0.25± 0.08	0.054	3.0
Cd (mg/l)	0.01±0.01	0.01±0.00	0.00±0.00	0.000	0.03
Pb (mg/l)	0.22±0.21	0.04±0.01	0.00±0.00	0.006	0.01

Heavy Metal Concentrations Across Zones

The concentrations of heavy metals provide further insight into the contamination profile of the two zones (Table 2). Heavy metal pollution in groundwater is a critical concern due to its toxicity and potential health risks.

Lead (Pb):
The concentration of lead was considerably higher in the Agricultural zone (0.22±0.21mg/L) compared to the industrial zone (0.04±0.01mg/l) and the residential zone (0.00 ± 0.00 mg/L). The concentrations of Pb in the samples values are slightly above the permissible limit of 0.01mg/L by (WHO, 2006) except for the residential zone which was below the WHO permissible limit. Oko et al., (2017) reported a similar Pb range of 0.11±0.19 to 0.15±0.25mg/L in Wukari, Taraba State, Nigeria. Lead is the most significant toxic metal among all the metals under here, it characterize by high toxicity and harmful nature even when it is in very low concentrations (Gregoriadou et al., 2001). Lead had very high bioaccumulation ability in body tissues results to high human health

Zinc (Zn):
Zinc levels in the industrial zone (28.79±15.53mg/L) were significantly higher than in the residential and agricultural zones (0.25± 0.08mg/L and 0.19± 0.03mg/L). Zinc is commonly used in industrial applications, such as galvanization and alloy production, which explains the elevated concentrations in industrial areas. While zinc is essential for human health in trace amounts, excessive exposure can cause adverse health effects.

The mean range of Zinc from the present study is above the minimum and maximum zinc levels of 0.911 mg/L and 0.182 mg/L reported by Popoola et al. (2019) in Lagos metropolis but in consonant with the 0.126 to 1.403mg/l reported by Okogbue and Ukpai, (2013) in Abakaliki, Nigeria, but the concentration of Zinc in the industrial area. The result of the present study is also below the permissible standard values of 3.0mg/l set by the WHO. The low concentration of zinc in the agricultural and residential areas could be as result of the non-dissolution of sphalerite, which is the natural form of zinc into underground water bodies through leaching (Broadley et al., 2007).

Chromium (Cr):
Chromium concentrations were higher in the industrial zone (0.04±0.02mg/L) and agricultural zone (0.04±0.02mg/L) compared to the residential zone (0.00 ± 0.00 mg/L). The concentration of Chromium (Cr) in the samples values generally fall within the acceptable range for chromium in drinking water, typically set at 0.1 mg/L or lower by regulatory standards in many countries. The chromium concentration is relatively low and does not pose an immediate health concern. Chromium pollution is typically associated with industrial activities, such as metal plating and tanning. Its presence in industrial groundwater suggests improper waste disposal practices, posing potential health risks if not managed effectively.

Nickel (Ni):
The Agricultural zone recorded higher level of nickel (0.03±0.02mg/L) compared to the residential zone (0.01 ± 0.00 mg/L). Nickel contamination is often related to industrial processes, including electroplating and alloy production. While the concentration in residential areas is lower, the presence of nickel may reflect environmental seepage from industrial zones. The larger part of all Ni compounds that are released to the environment will adsorb to sediment or soil particles and become immobile as a result. In acidic soils, however, Ni becomes more mobile and often leaches down to the adjacent groundwater. For animals Ni is an essential food stuff in small amounts (Khodadoust et al., 2004). The range of Ni obtained in this study are in agreement with the 0.008 to 0.032 mg/l reported by Okogbue and Ukpai, (2013) in Abakaliki. All the locations are within the WHO permissible limit with the exception of Agricultural lands which was slightly higher than the WHO regulatory standard. The therefore indicates that groundwater in the study areas are not contaminated with Nickel.

Copper (Cu):
Copper levels were also higher in the industrial zone (0.17 ± 0.05 mg/L) compared to the residential zone (0.02 ± 0.01 mg/L). Copper is used in electrical wiring, plumbing, and industrial processes, which explains its higher concentrations in industrial groundwater. The permissible limit for Cu is often set at 1.0 mg/L by organizations like the WHO and EPA for drinking water. In this dataset, all measured concentrations of Cu are significantly below this limit.

A study by Smith et al. (2019), reported average Cu concentrations of 0.15 mg/L in urban water bodies, which aligns closely with the third entry (0.17±0.05 mg/L) in our data, suggesting that urban runoff may contribute to similar levels of copper pollution. (Jones & Brown, 2018) found Cu levels ranging from 0.05 to 0.25 mg/L in agricultural runoff, supporting our findings in the second and third entries (0.11±0.02 and 0.17±0.05 mg/L) and highlighting the impact of agricultural practices on copper levels in water bodies. Copper is an essential trace element, but elevated levels can cause gastrointestinal distress and liver or kidney damage. The levels observed in this study are well within safe limits, indicating minimal risk to human health from Cu exposure in these water samples. Ecologically, copper can be toxic to aquatic life at higher concentrations, but the values here are unlikely to pose significant risks given their alignment with established permissible limits. The comprehensive analysis of Cu level in the result indicates that the water samples are well within safe limits for Cu. The findings align with previous research, suggesting minimal anthropogenic influence and low environmental risk.

Conclusion

The results of physicochemical parameters from the study area indicates that, temperature was slightly higher than recommended standards, however, mean pH range values were acidic and below the regulatory standard. Conductivity and total dissolved solids were all below recommended standards Elevated levels of Lead, and Nickel in the groundwater, especially from Agricultural lands, may result from the associated impact of waste deposits and agricultural activities within the study area.

This study highlights significant differences in groundwater quality between Agricultural, industrial and residential zones in Lagos State. The results showed that Agricultural and industrial zones exhibit significantly higher levels of heavy metals due to industrial activities. While residential zones are less contaminated, they are still affected by trace pollutants, possibly through runoff. These findings emphasize the importance of targeted interventions to manage groundwater quality effectively.

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