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RESEARCH ARTICLE

GEOCHEMICAL ASSESSMENT OF SOME POTENTIALLY TOXIC AND NON-ESSENTIAL ELEMENTS IN GROUNDWATER OF KADUNA POLYTECHNIC MAIN CAMPUS

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ABSTRACT

This study investigates the geochemical characteristics and potential contamination of groundwater within the Kaduna Polytechnic Main Campus. Piper plot analysis reveals that the water samples predominantly exhibit a Ca^{2+}–Mg^{2+}–Cl^{-}—SO_4^{2-} type, indicating a mixture of alkaline earth and strong acid anion concentrations. Electrical conductivity (EC) values in the samples ranged from 365 to 1790 µS/cm, reflecting variations in ion concentrations. Nitrate levels in some samples were alarmingly high, ranging from 27.20 mg/l to 131.00 mg/l, surpassing the WHO permissible limit of 45 mg/l. Arsenic concentrations varied between 0.015 and 0.125 mg/l, with certain samples exceeding the WHO guideline of 0.01-0.05 mg/l. Cadmium concentrations were particularly concerning, ranging from 0.604 mg/l to 0.766 mg/l, significantly above the WHO limit of 0.03 mg/l. Chromium concentrations ranged from non-detectable to 0.25 mg/l, with some samples exceeding the WHO limit of 0.05 mg/l. Nickel concentrations ranged from 0.078 mg/l to 0.128 mg/l, surpassing the WHO limit of 0.01 mg/l in all samples. Mercury concentrations were exceptionally high, ranging from 2.357 mg/l to 3.807 mg/l, far exceeding the WHO limit of 0.02 mg/l. These findings suggest that the groundwater quality within the Kaduna Polytechnic Main Campus is compromised by a range of emerging contaminants, likely stemming from anthropogenic activities such as improper waste disposal, agricultural practices, and nearby mechanical operations. Urgent intervention is required to mitigate potential health risks and protect the groundwater resources of the area.

KEYWORDS

Groundwater quality, nitrate contamination, heavy metals, Kaduna Polytechnic, emerging contaminants

1. INTRODUCTION

Groundwater is a critical resource that provides a significant portion of the world's potable water supply, especially in areas with limited surface water (Shuaibu et al., 2022). However, the quality of groundwater is increasingly compromised due to contamination from both natural and anthropogenic sources (Muhammad et al., 2024). In urban and industrial areas, human activities such as improper waste disposal, use of septic tanks and latrines, agricultural practices, and industrial operations have led to the introduction of potentially toxic and non-essential elements into the groundwater system (Li et al., 2020; Ullah et al., 2022). These contaminants can have severe implications for human health and the environment.

The increasing contamination of groundwater with potentially toxic and non-essential elements poses a significant threat to public health and the environment (Karunanidhi et al., 2021). At Kaduna Polytechnic Main Campus, the shallow depth of groundwater and inadequate waste management practices heighten the risk of contamination (Banks et al., 2020). The use of pesticides and herbicides in nearby farms, coupled with the disposal of used engine oils by auto mechanics, further contributes to the deterioration of groundwater quality. Despite the importance of groundwater to the campus community, there is limited data on the concentration of these harmful elements and their impact on water quality. This study seeks to fill this gap by providing a comprehensive geochemical assessment of groundwater quality in the study area.

Kaduna Polytechnic Main Campus, located in the urban heart of Kaduna, Nigeria, is no exception to these challenges. The campus is characterized by shallow groundwater, making it particularly vulnerable to contamination from surface activities. The lack of proper sanitation facilities, coupled with the proximity of auto mechanic workshops and local farms, exacerbates the risk of groundwater pollution. This study focuses on the geochemical assessment of potentially toxic and non-essential elements in the groundwater of Kaduna Polytechnic Main Campus, with the aim of identifying the sources, concentrations, and potential health risks associated with these contaminants.

1.1 Objectives of the study

The primary objective of this study is to assess the geochemical characteristics of groundwater in Kaduna Polytechnic Main Campus, with a specific focus on potentially toxic and non-essential elements. The specific objectives include:

- To determine the concentration of potentially toxic elements such as arsenic, lead, cadmium, chromium, and mercury in the groundwater.
- To assess the levels of non-essential elements such as aluminum, iron, and zinc in the groundwater.
- To evaluate the physicochemical parameters (pH, electrical conductivity, turbidity, temperature, and total dissolved solids) that influence groundwater quality.

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- To identify the sources of groundwater contamination in the study area.
- To assess the health risks associated with the consumption of contaminated groundwater.
- To provide recommendations for mitigating groundwater contamination and improving water quality.

2. Geology

The study area exhibits a diverse array of rock types, including granites, schists, quartzites, and gneisses (Jibril et al., 2024). However, the dominant geological feature is the presence of migmatitic gneiss with notable amphibolite intrusions (figure 1), characteristic of the Basement Complex of northern Nigeria (Muhammad et al., 2024). The region is also marked by significant intrusions of quartz veins, pegmatites, and aplite dykes. The exposed outcrops in this area showcase a variety of geological structures, both primary and secondary, and range in size from small to large, often accompanied by numerous boulders. The rocks in the area have undergone extensive weathering, deformation, and metamorphism, leading to the formation of complex geological structures and the breakdown of certain rock types. These metamorphic processes have significantly altered the original rock formations, adding to the complexity and diversity of the geological features observed in the study area.

2.1 Hydrology and hydrogeological conditions of the study area

The hydrology and hydrogeological conditions of the Kaduna Polytechnic Main Campus are closely influenced by the region's geology and climatic conditions (Ologunorisa et al., 2021). The area is underlain predominantly by migmatitic gneiss, granites, and schists, all characteristic of the Basement Complex of northern Nigeria (Wali et al., 2021). These rock types are generally known for their low primary porosity and permeability, which limit the natural storage and movement of groundwater. However, secondary porosity, created through extensive weathering, fracturing, and faulting of these rocks, plays a crucial role in the area's groundwater dynamics.

In the study area, the weathered and fractured zones, especially within the migmatitic gneiss, are the primary aquifers (Daramola et al., 2022), allowing for the storage and transmission of groundwater. These zones are often shallow and discontinuous, leading to localized aquifer systems that are highly sensitive to both seasonal fluctuations and anthropogenic activities. The presence of quartz veins, pegmatites, and aplite dykes can also influence the groundwater flow by creating barriers or preferential pathways, further complicating the hydrogeological conditions.

The climatic conditions of the region, characterized by a tropical savanna climate with distinct wet and dry seasons, significantly impact the hydrology of the area (Garba and Abubakar, 2023). During the rainy season, which typically occurs between April and October, the area receives substantial rainfall that contributes to groundwater recharge, especially in areas where the weathered zones are well-developed. However, the infiltration capacity is often reduced due to the presence of impervious rock formations and the nature of the soil cover, leading to limited recharge potential.

Conversely, during the dry season, the water table tends to drop due to reduced recharge and increased evaporation rates. The shallow depth to groundwater makes the aquifers more susceptible to contamination from surface activities, such as improper waste disposal and the use of pesticides and herbicides in nearby farms. Additionally, the proximity of septic tanks, latrines, and auto mechanic workshops poses a significant risk of introducing pollutants into the groundwater, further affecting its quality and availability.

Overall, the hydrology and hydrogeology of the Kaduna Polytechnic Main Campus are complex and highly variable, reflecting the interplay between the area's geological framework, climatic conditions, and human activities. Understanding these dynamics is crucial for sustainable groundwater management and addressing the challenges of contamination in the study area.

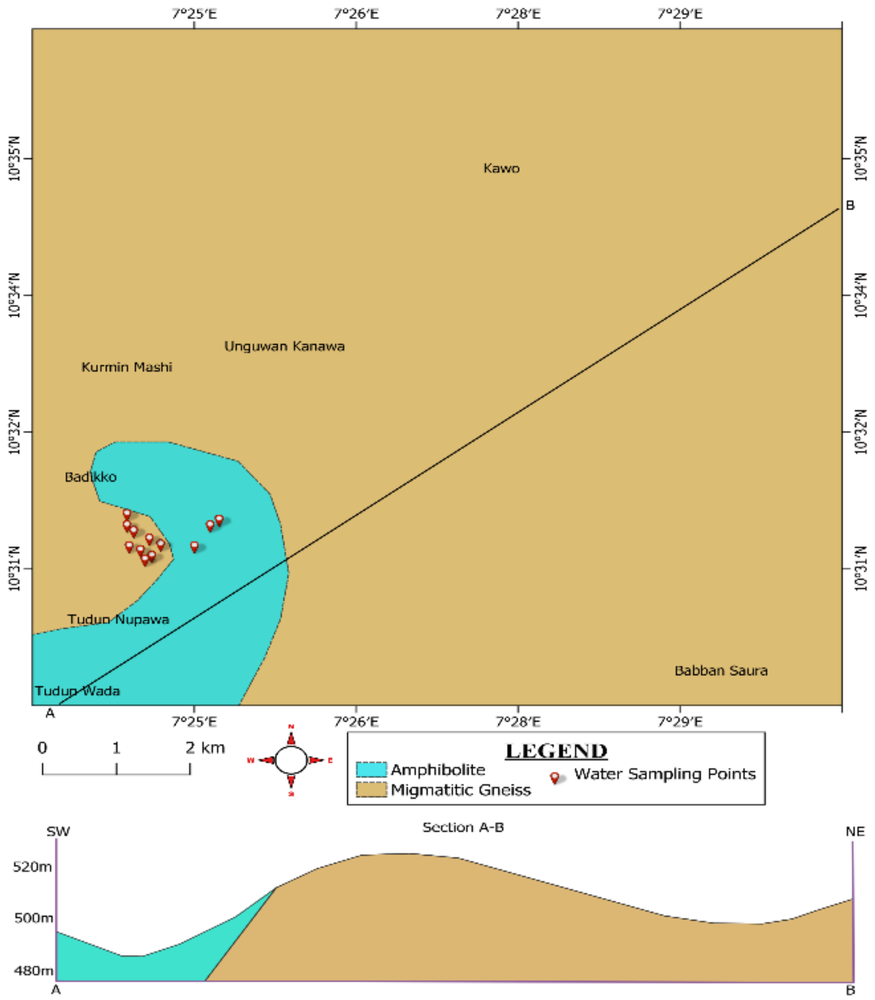

Figure 1: Geological mapof Kaduna Polytechnic and environs showing water sampling locations (Jibril et al., 2024)

3. Methodology

The study was conducted within a specific geographic region characterized by its unique geological and hydrological features. The coordinates of the sampling sites were recorded using a GPS device to ensure precise location data. The area was selected based on its relevance to the study's objectives, including the presence of potential contamination sources such as agricultural activities, industrial operations, or natural mineral deposits.

3.1 Sampling design

The sampling design was structured to capture a comprehensive picture of groundwater quality across the study area. A total of 12 samples (9 boreholes and 3 wells) were selected for sampling, with their locations spread out to cover different hydrogeological zones. The sampling sites were chosen based on accessibility, depth of the wells, and proximity to potential contamination sources.

3.2 Sample collection

3.2.1 Sampling procedures

Groundwater samples were collected following standardized procedures to prevent contamination. The boreholes were pumped for a few minutes before sample collection to ensure that the water samples were representative of the aquifer and not stagnant water in the well casing. Samples were collected in pre-cleaned polyethylene bottles, which were rinsed with the groundwater from each well before final collection.

3.2.2 Sample preservation and transportation

To preserve the integrity of the samples, they were immediately cooled to 4°C and transported to the laboratory in ice-packed coolers. For certain parameters, such as heavy metals, the samples were acidified with nitric acid to prevent metal precipitation and adsorption onto the container walls. All samples were analyzed within 48 hours of collection to ensure accurate results.

3.3 Laboratory analysis

3.3.1 Heavy metals analysis

The concentration of heavy metals, including Arsenic (As), Manganese (Mn), Cadmium (Cd), Chromium (Cr), Lead (Pb), Nickel (Ni), Mercury (Hg), Aluminum (Al), Iron (Fe), Copper (Cu), and Zinc (Zn), was determined using Atomic Absorption Spectrophotometry (AAS). This method was chosen for its sensitivity and accuracy in detecting trace levels of metals in water samples. Calibration of the AAS was performed using standard solutions, and quality control measures included the use of blanks and replicate samples.

3.3.2 General water quality indicators

Parameters such as pH, Electrical Conductivity (EC), Temperature, Turbidity, and Total Dissolved Solids (TDS) were measured using a combination of field meters and laboratory instruments. pH and Temperature were measured on-site using a calibrated portable pH meter and thermometer, respectively. EC was determined using a conductivity meter, while Turbidity and TDS were measured using a turbidimeter and a gravimetric method, respectively.

3.3.3 Ionic constituents analysis

The concentrations of major cations (Sodium, Potassium, Calcium, Magnesium) and anions (Phosphate, Sulfate, Chloride, Nitrate, Bicarbonate) were analyzed using Ion Chromatography (IC) and Titration methods. Sodium and Potassium were analyzed using Flame Photometry, while Calcium and Magnesium were determined by complexometric titration with EDTA. Anions were analyzed using IC, with specific detection methods for each ion to ensure accuracy.

3.4 Data analysis

3.4.1 Comparison with WHO standards

The concentrations of the analyzed parameters were compared with the World Health Organization (WHO) drinking water standards to assess the safety and suitability of the groundwater for consumption (WHO, 2018). Any deviations from the permissible limits were noted and discussed in terms of potential health risks and environmental impacts.

3.4.2 Geospatial analysis

Geospatial analysis was conducted using Geographic Information System (GIS) software to map the spatial distribution of the water quality parameters across the study area. This analysis helped in identifying potential hotspots of contamination and understanding the spatial variability of groundwater quality.

4. Results and Discussion

4.1 Hydrochemical facies analysis using Piper Plot

The Piper plot is a trilinear diagram that visually represents the chemistry of water samples based on the major cations (calcium, magnesium, sodium, and potassium) and anions (carbonate, bicarbonate, chloride, and sulfate). The position of each sample on the plot reveals the dominant hydrochemical facies.

As illustrated in the Piper plot (Figure 2), the groundwater samples from the study area primarily fall within the region where the Ca-Mg-Cl-SO_4 facies dominate. This suggests that the groundwater chemistry is mainly influenced by the dissolution of calcium and magnesium-bearing minerals, as well as the presence of chloride and sulfate ions. The presence of these ions may indicate interactions with evaporite minerals, such as gypsum, or anthropogenic influences like agricultural runoff and industrial activities (Tyagi and Sarma, 2021).

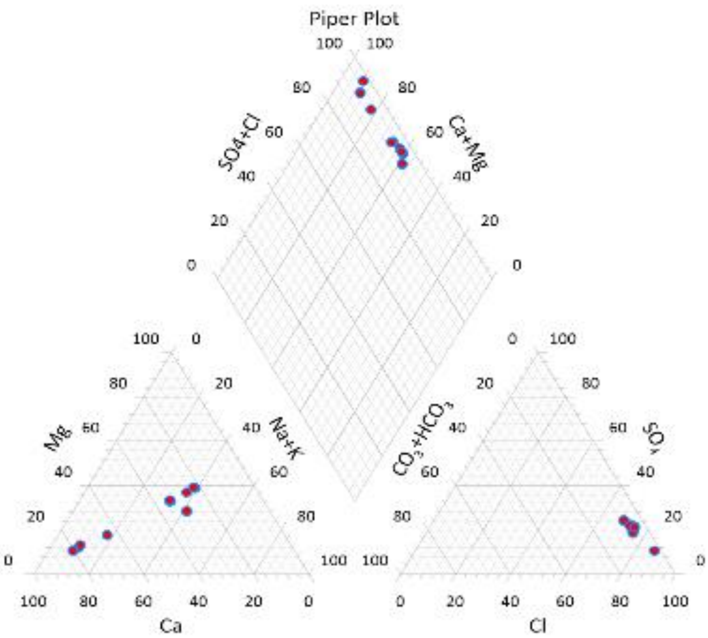

Figure 2: Piper plot showing hydrochemical facies of the groundwater in the study area

4.2 Interpretation of Schoeller diagram

The Schoeller diagram (figure 2) is another tool used to visualize the ionic composition of water samples. It plots the concentrations of major ions on a logarithmic scale, allowing for the comparison of water chemistry across different samples (Zidi et al., 2020).

Figure 2 displays the Schoeller diagram for the groundwater samples. The diagram indicates that calcium (Ca^{2+}) and chloride (Cl^{-}) are the most prevalent ions across the samples, followed by magnesium (Mg^{2+}) and sulfate (SO_4^{2-}). The relatively high concentrations of Ca^{2+} and Mg^{2+} suggest significant contributions from calcium-rich igneous rocks dissolution, while the Cl^{-} and SO_4^{2-} levels point towards potential inputs from industrial discharges (Vallejos et al., 2020).

The pattern observed in the Schoeller diagram aligns with the hydrochemical facies identified in the Piper plot, further confirming that the groundwater in the study area is primarily characterized by a Ca-Mg-Cl-SO_4 water type.

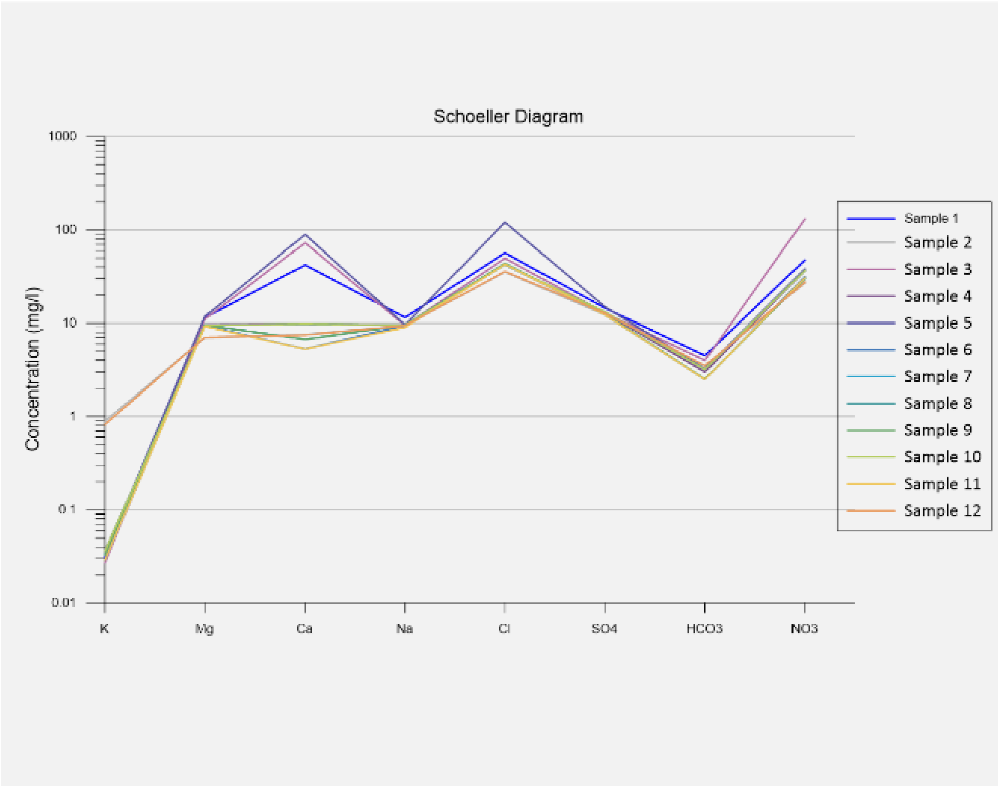

Figure 3: Schoeller diagram showing ionic composition of water samples in the area

4.3 Geochemical characteristics and water quality parameters

The analysis of groundwater quality in the study area involved a comprehensive evaluation of various physicochemical parameters, including heavy metals, general water quality indicators, and ionic constituents. The parameters analyzed include Sodium (Na+), Potassium (K+), Calcium (Ca2+), Magnesium (Mg2+), Phosphate (PO-4), Sulfate (SO42-), Chloride (Cl-), Nitrate (NO3-), and Bicarbonate (HCO3-). Table 3 focuses on the concentration of heavy metals such as Arsenic (As), Manganese (Mn), Cadmium (Cd), and others, which are critical due to their potential health risks even at low concentrations. The second table assesses parameters like pH, Electrical Conductivity (EC), Temperature, Turbidity, and Total Dissolved Solids (TDS), which are essential for determining the overall water quality and its suitability for consumption. The third table examines the presence of key ions, including Sodium (Na+), Potassium (K+), Calcium (Ca2+) as shown in table 4.2, and others, providing insights into the geochemical processes influencing groundwater composition. By comparing the results with World Health Organization standards (2018), this analysis aims to identify potential contamination sources, assess the water's safety for human use, and recommend necessary treatment and management strategies.

4.3.1 Physical properties

Table 1: Physical characteristics of water samples

Sample	Sample Coordinates	pH	EC (µS/cm)	Temp (⁰C)	Turbidity	TDS (Mg/l)
1	10◦31´26"*N* 7◦25´12"E	6.50	949.00	29.90	3.00	607.4
2	10◦31´40"*N* 7◦25´23"E	6.25	368.00	29.80	3.00	235.5
3	10◦31´37"*N* 7◦25´19"E	6.27	915.00	29.50	4.00	585.6
4	10◦31´27"*N* 7◦24´57"E	6.60	549.00	29.32	4.00	351.4
5	10◦31´26"*N* 7◦24´43"E	6.67	1780.00	29.80	6.00	1139.2
6	10◦31´43"*N* 7◦24´42"E	6.49	547.00	29.40	2.00	350.08
7	10◦31’37"N 7◦24’42E	6.24	495.00	29.30	3.00	654.2
8	10◦31’34"N 7◦24’45E	6.48	593.00	28.98	4.00	575.7
9	10◦31’30"N 7◦24’52E	6.30	578.00	29.45	5.00	622.6
10	10◦31’21"N 7◦24’53E	6.67	1790.00	29.90	6.00	1124.3
11	10◦31’24"N 7◦24’48E	6.50	365.00	29.70	3.00	255.4
12	10◦31’19"N 7◦24’50E	6.50	366.00	29.50	3.00	255.5
	W.H.O (2018) standard permissible limit	6.5-8.5	1000	26.34	0-5	500

Turbidity, indicating the clarity of water, ranges from 2 NTU to 6 NTU, with some samples exceeding the WHO permissible limit of 0-5 NTU. Elevated turbidity levels suggest the presence of suspended particles like silt, clay, or organic matter, possibly from surface runoff or disturbed aquifers, which could shield harmful microorganisms from disinfection processes. Total Dissolved Solids (TDS) in the samples range from 235.5 mg/l to 1139.2 mg/l, with some samples exceeding the WHO limit of 500 mg/l. High TDS levels suggest a high mineral content, potentially affecting the taste of the water and indicating the presence of contaminants from natural or human-induced sources such as agriculture and industry.

4.3.2 Chemical characteristics

Groundwater chemistry is influenced by the dissolution of minerals from the surrounding rock and soil, as well as by human activities such as agriculture and industrial processes. The presence of certain ions in the water can provide insights into the underlying geology, the potential sources of contamination, and the overall water quality.

The groundwater analysis reveals (table 4.2) that Sodium (Na+) concentrations range from 9.02 mg/l to 11.51 mg/l, which is significantly lower than the WHO permissible limit of 200 mg/l. This suggests minimal saltwater intrusion and limited anthropogenic contamination. Potassium (K+) levels are also low, ranging from 0.027 mg/l to 0.893 mg/l, far below the WHO limit of 200 mg/l, indicating a limited presence of potassium-bearing minerals like orthoclase and mica. Calcium (Ca2+) concentrations vary from 5.28 mg/l to 89.20 mg/l, within the WHO limit of 200 mg/l, and this variation likely reflects differences in local geology and mineral composition, particularly the presence of calcite and gypsum.

Magnesium (Mg2+) levels in the samples are consistently within safe limits, ranging from 7.01 mg/l to 12.14 mg/l, which aligns with the uniform distribution of magnesium-rich minerals such as dolomite in the aquifers. Conversely, Phosphate (PO-4) concentrations are alarmingly high, ranging from 6.93 mg/l to 10.89 mg/l, significantly exceeding the WHO limit of 0.01 mg/l. This elevated phosphate level indicates substantial agricultural runoff, posing potential risks to both human health and aquatic ecosystems. Sulfate (SO42-) concentrations, on the other hand, are low, ranging from 12.10 mg/l to 15.00 mg/l, well within the WHO permissible limit of 250 mg/l, suggesting minimal industrial pollution.

Chloride (Cl-) levels in the groundwater vary from 35.45 mg/l to 120.53 mg/l, within the WHO limit of 250 mg/l, with the variation likely influenced by local geology and agricultural practices. Nitrate (NO3-) concentrations range from 27.20 mg/l to 131.00 mg/l, with some samples exceeding the WHO limit of 45 mg/l, indicating a significant agricultural impact that could pose health risks, particularly for infants. Finally, Bicarbonate (HCO3-) levels are low, ranging from 2.50 mg/l to 4.50 mg/l, well below the WHO limit of 150 mg/l, suggesting limited carbonate dissolution or a high rate of carbonate precipitation in the aquifers.

The concentration of NO3 is within the WHO (2018) permissible limit of 45 mg/l in most of the campus except in sample 1 and 3 where it is 47.60 mg/l and 131.00 respectively. Excess of nitrate can affect how the blood carries oxygen. Nitrate can turn hemoglobin (the protein in blood that carries oxygen) into methemoglobin. High level can turn skin into a bluish or gray color and cause more serious health effects like weakness excess heart rate, fatigue, and dizziness..

Table 2: Concentration of major cations and anions in the water samples

Sample	Sample coordinates	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	PO_4 (mg/l)	SO_4^{2-} (mg/l)	Cl^- (mg/l)	NO_3^- (mg/l)	HCO_3^- (mg/l)
1	10°31´26"N 7°25´12"E	11.51	0.031	42.08	11.48	6.93	14.55	56.72	47.60	4.50
2	10°31´40"N 7°25´23"E	9.43	0.893	7.57	7.01	9.16	12.30	35.45	27.20	3.50
3	10°31´37"N 7°25´19"E	9.43	0.027	72.58	11.08	10.50	12.90	49.63	131.00	4.00
4	10°31´27"N 7°24´57"E	9.47	0.036	9.76	9.60	10.70	12.90	42.54	36.67	3.00
5	10°31´26"N 7°24´43"E	9.58	0.034	89.20	11.82	8.72	15.00	120.53	38.32	3.25
6	10°31´43"N 7°24´42"E	9.47	0.029	5.29	9.43	8.52	12.30	42.54	31.60	2.50
7	10°31'37"N 7°24'42E	9.54	0.033	6.72	9.56	8.22	12.50	43.62	30.06	2.52
8	10°31'34"N 7°24'45E	9.48	0.036	9.78	9.40	10.84	13.20	42.56	36.88	3.20
9	10°31'30"N 7°24'52E	9.40	0.064	9.84	9.66	10.89	12.82	42.74	42.94	3.40
10	10°31'21"N 7°24'53E	9.43	0.031	70.68	12.14	10.56	12.10	48.43	34.14	4.00
11	10°31'24"N 7°24'48E	9.02	0.029	5.28	9.24	8.64	12.30	42.82	30.80	2.50
12	10°31'19"N 7°24'50E	9.43	0.824	7.47	7.06	9.16	12.80	35.85	27.60	3.50
	W.H.O (2018) Standard permissible limit	200	200	200	20	0.01	250	250	45	150

Table 3: Concentration of elements considered to be toxic and non-essential

Sample	Sample coordinates	As (mg/l)	Mn (mg/l)	Cd (mg/l)	Cr (mg/l)	Pb (mg/l)	Ni (mg/l)	Hg (mg/l)	Al (mg/l)	Fe (mg/l)	Cu (mg/l)	Zn (mg/l)
1	10°31´26"*N* 7°25´12"E	0.125	0.385	0.746	0.000	0.000	0.127	3.807	0.011	0.013	0.012	0.034
2	10°31´40"*N* 7°25´23"E	0.116	0.202	0.756	0.250	0.021	0.106	2.945	0.005	0.005	0.009	0.042
3	10°31´37"*N* 7°25´19"E	0.015	0.216	0.734	0.082	0.030	0.114	2.894	0.026	0.025	0.003	0.034
4	10°31´27"*N* 7°24´57"E	0.073	0.189	0.717	0.000	0.000	0.097	2.475	0.032	0.013	0.017	0.071
5	10°31´26"*N* 7°24´43"E	0.034	0.187	0.704	0.000	0.002	0.098	2.468	0.014	0.015	0.006	0.054
6	10°31´43"*N* 7°24´42"E	0.061	0.185	0.705	0.000	0.013	0.087	2.453	0.004	0.012	0.015	0.057
7	10°31'37"N 7°24'42E	0.044	0.177	0.698	0.067	0.012	0.083	2.448	0.012	0.015	0.005	0.059
8	10°31'34"N 7°24'45E	0.085	0.199	0.732	0.083	0.000	0.087	2.484	0.033	0.013	0.016	0.073
9	10°31'30"N 7°24'52E	0.063	0.178	0.724	0.000	0.014	0.097	2.498	0.042	0.018	0.027	0.081
10	10°31'21"N 7°24'53E	0.071	0.192	0.762	0.083	0.000	0.078	2.357	0.044	0.016	0.019	0.061
11	10°31'24"N 7°24'48E	0.032	0.172	0.604	0.000	0.012	0.099	2.480	0.016	0.015	0.008	0.054
12	10°31'19"N 7°24'50E	0.118	0.304	0.766	0.242	0.014	0.128	2.945	0.005	0.005	0.009	0.042
	W.H.O (2018) Standard Maximum Permissible Limit	0.01-0.05	0.5	0.03	0.05	0.05	0.01	0.02	0.2	0.3	1.5	5

4.3.3 Concentration of heavy metals in groundwater

The analysis of groundwater reveals concerning levels of heavy metal contamination (table 3), starting with Arsenic (As), which ranged from 0.015 mg/l to 0.125 mg/l. Several samples exceed the WHO permissible limit of 0.01-0.05 mg/l, suggesting contamination likely from the weathering of arsenic-bearing minerals in the geological formations. Long-term exposure to arsenic is associated with severe health issues, including skin lesions, cancer, and cardiovascular diseases (Zeng and Zhang, 2020). Chromium (Cr) levels ranged from non-detectable to 0.25 mg/l, with some samples exceeding the WHO limit of 0.05 mg/l. The presence of chromium could stem from industrial activities such as leather tanning or natural weathering of chromium-bearing rocks. Hexavalent chromium, a particularly toxic and carcinogenic form, poses significant health risks (Sharma et al., 2022).

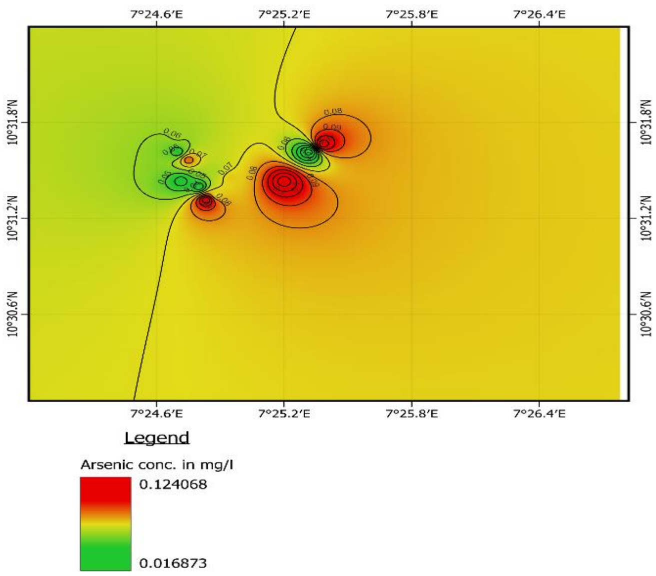

Figure 4: Iso-concentration map showing spatial conc. of Arsenic (As) in the study area

Lead (Pb) concentrations were generally low, with most samples showing non-detectable levels. However, a few samples had lead levels slightly above the WHO limit of 0.05 mg/l, potentially due to corrosion of lead-containing pipes or industrial activities. Lead exposure is particularly dangerous for children, leading to cognitive impairment and developmental delays (Al-Saleh et al., 2020; Heidari et al., 2021). Nickel (Ni) concentrations ranged from 0.078 mg/l to 0.128 mg/l, exceeding the WHO limit of 0.01 mg/l in all samples. Nickel contamination could be from the natural erosion of rocks or industrial activities such as electroplating, with long-term exposure leading to dermatitis, respiratory issues, and an increased risk of cancer (Kumar et al., 2021).

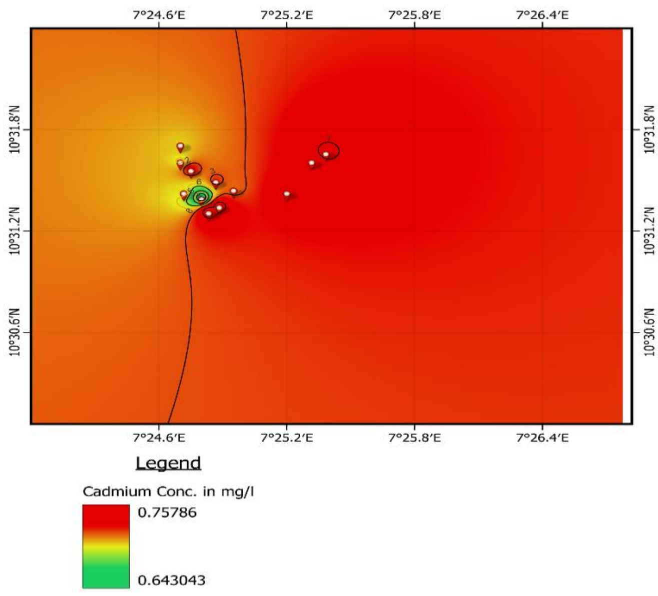

Figure 5: Iso-concentration map showing spatial conc. of Cadmium (Cd) in the study area

Mercury (Hg) levels ranged from 2.357 mg/l to 3.807 mg/l, significantly exceeding the WHO limit of 0.02 mg/l. This contamination likely originates from industrial pollution, such as mining and fossil fuel combustion. Mercury is highly toxic and can cause severe neurological damage, especially in developing fetuses and young children (Saavedra et al., 2021). In contrast, Aluminum (Al), Iron (Fe), Copper (Cu), and Zinc (Zn) levels were relatively low, with all concentrations well below their respective WHO limits. Although aluminum, iron, copper, and zinc are naturally occurring and essential to some extent, their presence in the analyzed samples does not pose immediate health risks (Ustaoğlu & Islam, 2020). However, excessive exposure to these elements over time could lead to other health concerns.

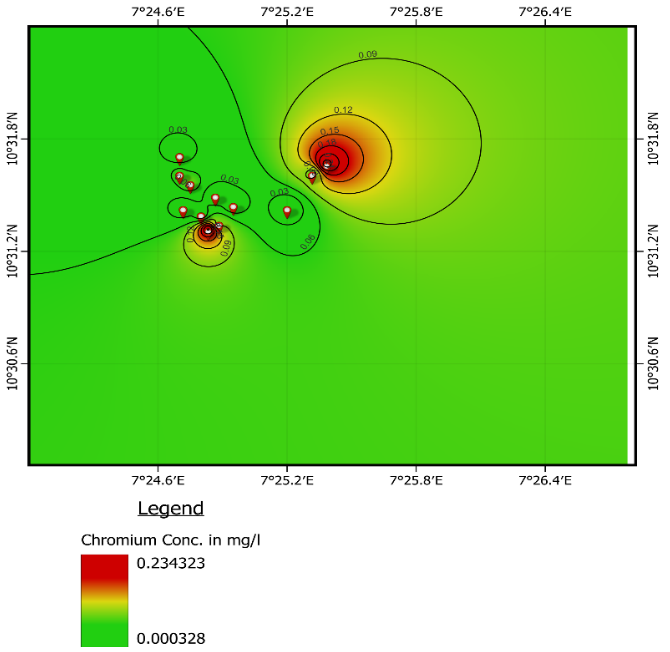

Figure 6: Iso-concentration map showing spatial conc. of Chromium (Cr) in the study area

The analysis of the water samples reveals that several heavy metals exceed the WHO permissible limits, posing significant health risks to the local population. The most concerning elements include arsenic, cadmium, mercury, nickel, and chromium. Long-term exposure to these contaminants can lead to severe health issues, including cancer, neurological disorders, kidney damage, and developmental problems in children. Immediate measures are necessary to mitigate these risks, such as water treatment, monitoring, and the identification of alternative water sources.

4.4 Emerging contaminants and their impact on groundwater quality in the study area

The groundwater quality within the Kaduna Polytechnic Main Campus is potentially influenced by a range of emerging contaminants. These contaminants arise from various anthropogenic activities, including improper waste disposal, agricultural practices, and local mechanical operations.

4.4.1 Improper waste disposal

The lack of proper sanitation facilities has led to the accumulation of waste in open spaces and drainage systems across the campus. This waste includes household garbage, food waste, and plastic materials, which can leach harmful substances into the groundwater. The presence of heavy metals such as lead (Pb), mercury (Hg), and cadmium (Cd), as indicated in the groundwater analysis, could be traced back to leachate from improperly managed waste. These heavy metals pose serious health risks, including neurological damage, kidney failure, and increased cancer risk.

4.4.2 Shallow depth to groundwater

The shallow depth of groundwater in the study area exacerbates the risk of contamination. When the water table is close to the surface, it becomes more susceptible to pollutants from surface activities, including waste from septic tanks, latrines, and surface runoff. Contaminants such as nitrates (NO_3^-) and phosphates (PO_4^{3-}) from agricultural runoff and waste seep into the shallow aquifers, degrading water quality and making it unsafe for consumption.

4.4.3 Septic tanks and latrines

The widespread use of septic tanks and latrines without adequate containment and treatment can lead to the infiltration of pathogens, organic compounds, and chemical pollutants into the groundwater. The presence of nitrates and elevated levels of total dissolved solids (TDS) in the groundwater suggests contamination from human waste. Nitrate contamination is particularly concerning due to its link to methemoglobinemia or "blue baby syndrome" in infants and other chronic health conditions in adults.

4.4.4 Agricultural practices

The use of pesticides and herbicides on local farms within and around the campus contributes significantly to groundwater contamination. These chemicals contain harmful substances, including organophosphates and chlorinated compounds, which can persist in the environment and accumulate in groundwater. The elevated levels of certain ions such as sodium (Na^+), potassium (K^+), and chloride (Cl^-) in the groundwater suggest agricultural runoff as a potential source of contamination. Prolonged exposure to these chemicals can lead to severe health issues, including endocrine disruption and increased cancer risk.

4.4.5 Impact of used engine oils from auto mechanics

Nearby auto mechanics' activities, particularly the improper disposal of used engine oils, pose another significant threat to groundwater quality. Engine oils contain a mixture of hydrocarbons and heavy metals, which can seep into the soil and eventually reach the groundwater. The detection of hydrocarbons and heavy metals like chromium (Cr) and nickel (Ni) in the groundwater analysis indicates possible contamination from these mechanical workshops. Exposure to these pollutants can result in toxic effects on the liver, kidneys, and central nervous system.

4.4.6 Combined impact of emerging contaminants

The cumulative effect of these emerging contaminants on groundwater quality cannot be underestimated. The interaction of multiple pollutants can lead to the formation of more toxic compounds, exacerbating health risks. For example, the presence of heavy metals in combination with nitrates can enhance the toxicity of the water, leading to more severe health outcomes for the campus population.

In conclusion, the groundwater quality at Kaduna Polytechnic Main Campus is under significant threat from various emerging contaminants linked to human activities. Addressing these issues requires a comprehensive approach, including improving waste management practices, controlling agricultural runoff, ensuring proper sanitation infrastructure, and regulating mechanical workshop activities.

5. Conclusion

The geochemical assessment of groundwater at Kaduna Polytechnic Main Campus has revealed significant contamination by heavy metals, with concentrations of arsenic, cadmium, mercury, nickel, and chromium exceeding WHO guidelines. These findings indicate that both natural geological processes and human activities, such as industrial operations and agricultural practices, are contributing to the degradation of groundwater quality in the area. The health risks associated with these contaminants highlight the need for immediate and sustained interventions to protect the campus community.

Recommendations

Pollution Source Control

Implement strict regulations to control and manage waste disposal from auto mechanic workshops and other industrial activities near the campus. Proper disposal facilities and waste collection systems should be established to prevent the release of heavy metals into the environment.

Sanitation and waste management

Upgrade and maintain sanitation facilities on campus to reduce the risk of contamination from septic tanks and latrines. Establish a solid waste management system to prevent the improper disposal of hazardous materials, including electronic waste and batteries.

Groundwater Treatment

Install advanced water treatment systems capable of removing heavy metals from groundwater before it is used for drinking and other purposes. Technologies such as reverse osmosis, ion exchange, and activated carbon filtration can be effective in reducing heavy metal concentrations.

Public Awareness and Education

Conduct awareness campaigns to educate the campus community about the risks associated with heavy metal contamination and the importance of proper waste disposal practices. Encourage the adoption of safer agricultural practices to reduce the introduction of heavy metals into the groundwater.

Further Research and Monitoring

Continue monitoring groundwater quality to assess the effectiveness of implemented measures and detect any changes in contaminant levels. Further research should be conducted to identify specific sources of heavy metal contamination and develop targeted strategies for remediation.

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