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QUANTIFICATION AND HEALTH RISK ASSESSMENT OF HEAVY METALS IN GROUNDWATER AROUND MINING SITES IN JEMA'A LOCAL GOVERNMENT AREA, KADUNA STATE, NIGERIA

AKAWU HARUNA ISAIAH; KIZITO WEYHAM GABRIEL; & ABAGAI ROSE TAKAI

[1,2]Biology Department Kaduna State College of Education GidanWaya, Kafanchan

Corresponding Author: isaiahharunaakawu@gmail.com

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Abstract

Jema'a Local Government Area is notable for decades of mining activities in Kaduna State, Nigeria. This mining activity increases the potentials for groundwater contamination and health risk impact. This study quantifies and assessed health risk of physico-chemical parameters (with respect to heavy metals) in groundwater around mining sites in Jema'a LGA from April to September 2024. Water and sediment samples were collected bimonthly and analyzed for physico-chemical parameters namely temperatures, pH, salinity, conductivity, Total dissolve solids, dissolve oxygen, transparency, nitrate, phosphate, copper, cadmium, lead and zinc. Measurements were done using electronic meter and Atomic Absorption Spectrophotometer (AAS). Data obtained were subjected to analysis of variance (ANOVA), Duncan multiple range test and Pearson correlation coefficient.All parameters measured were within WHO permissible limit.

Introduction

Groundwater is a major source of water for rural dwellers. Groundwater in rural areas is often impacted by several factors, mining, leachates and agro-allied chemicalthat may pose health related issues (Olagunju et al.,2020; Eyibio-Olaifa et al., 2024). Precipitation and run-off dissolves other waste chemicals from dumpsites, mining areas and industrial areas and leached into groundwater and soil which are then used by residents (Sulaimon et al., 2015). The toxicity of such dissolved chemicals depends on the composition of the chemical and

Results revealed that air temperature ranged from 23.7-31.9°C; surface water temperature, 25.5-31.9°C; pH, 6.60-8.22; salinity, 122-150.5 ppm; conductivity, 254.4-312.67 µmhoS/cm; total dissolve solids, 205.05-219.33 ppm; dissolve oxygen, 3.59-11.04 mg/L; transparency, 26.4-49.11 cm; nitrate, 0.06-8.12 mg/L; phosphate, 0.22-0.35 mg/L and copper, 0.002-0.04 mg/L showed significant ($p<0.05$) mean temporal variation, while zinc in surface water 0.025-0.30 mg/L; lead 0.04-0.06 mg/kg; copper 0.03-0.04 mg/kg and zinc in sediment 0.12-0.17 mg/kg did not show significant ($p>0.05$) temporal difference. Cadmium and lead were below detectable limit in groundwater during this study. There were high negative correlation between water transparencies and total dissolve solids content ($r = -.76$). The result suggest that groundwater around mining sites in Jema'a LGA showed early signs of pollution while health risk assessment showed low health risk, underscoring the need for frequent and comprehensive health risk assessment to evaluate potential bioaccumulation and biomagnification of this pollutants.

Key words: groundwater quality, mining impact, heavy metals, Jema'a LGA and pollution.

Its physical properties(Olagunju et. al., 2020) which is capable of creating health concerns to both humans and the environment.Physicochemical characteristics include temperatures, pH, salinity, conductivity, Total dissolve solids, dissolve oxygen, transparency, nitrate, phosphate, copper, cadmium, lead and zinc.

In rural areas of Jema'a local government area, water bodies(streams and rivers) are usually the sources of water for both domestic and mining activities. These water bodies are constantly impacted by materials from the mining activities leading to contamination of groundwater (Olagunju et. al., 2020). Contamination of groundwater by heavy metals is a potential environmental concern worldwide, posing significant environmental threat because of their non-degradable nature and toxicity (Hashem et al., 2017; Ojo, 2023). Increase industrial development fostering economical growth has resulted in aggravated concern for natural resources such as soil and water in many countries (Abbasnia et al., 2018). Industrial and artisanal mining activities are one of the many anthropogenic activities contributing to these increased concentrations of heavy metals in the environment (Mohammadi et al., 2019a). In Jema'a Local Government, Kaduna State, mining operations have been ongoing for the past five decades leading to the contamination of both water and soil with mining and mineral residues which may include heavy metals. These heavy metals if present in irrigation water mayaccumulate in vegetables posing health risk both to the environment and humans (Alloway, 2013). Although low levels of certain heavy metals such as copper (Cu) and zinc (Zn) are necessary for health, others such as Pb and Cd, even at low levels, are capable of causing serious health effects, like cancer development, cardiovascular diseases, increased blood pressure, and several other health concerns (Li et al., 2016). Although, heavy metals and other metalloids are natural structural part of the earth's crust having a density greater than 5g/cm3. Many of these heavy metals and metalloids are environmentally persistent and non-degradable contaminants (Ahmad et al., 2019). They find their way to the soil surface either through irrigation or runoff. Contaminated water from mining activities can then be absorbed by plant roots and further distributed and accumulated into their edible and non-edible parts, posing an increase health risk to the food chain (Alsafran et al., 2021).

Mining activities has been on the increase in Jema'a LGA and its adjoining communities due to its large mineral deposits. These activities span through decades with both artisanal mining and industrial mining activities. Heavy metals are a major group of pollutants that arenot easily degradable in nature. Their introduction and accumulation through food chain poses significant health risk in both humans and animals resulting in cases such as organ damage and cancers (Qasemi et al., 2018; Ahmad et al.,2019). Many human diseases such as neurological disorders, cancers, kidney problems, high blood pressures are due to exposure to environmental pollutants such as heavy metals (Basma and Alhogbi, 2017). This health related factors of heavy metal contamination and their bioaccumulation properties should instigate several researches on heavy metal accumulation especially in mining areas in Jema'a. Although several environmental researches were carried out in Jema'a Local Government Area of Kaduna state, such as Historical studies of mining activities which were conducted since 1975. Despite the importance of quantifying and tracing the heavy metal contamination in the food chain, there was no comprehensive study done to quantify heavy metals and their related health risk in groundwater around mining sites in Jema'a local Government Area, Kaduna State. As such this research is aimed at evaluating the physicochemical conditionof groundwater around mining sites in Jema'a local Government Area of Kaduna State to ascertain its health risk potentials.

MATERIALS AND METHODS

Study Area

This study was conducted in Jema'a LGA, in Kaduna State, Nigeria. This region has a long history of artisanal and industrial mining activities. The terrain is hilly with streams and rivers as sources of both agricultural and domestic water. Over the past decades this water sources were impacted directly and indirectly influenced by mining operations making them important for groundwater quality assessment.

Sampling Stations

Six sampling stations were selected due to their high proximity to mining activitiesand there overall community reliance for groundwater resources.

Station 1. This is located at Bakin Kogi Kaninkon (9.48467, 8.27405). This area is hilly with elevated highlands and water sources includes rivers and streams where mining activities are carried out

Station 2. This islocated in between mile-one village and pasakori axis, along KagoroNindem hills the entry point to Gidan waya Community (9.48205, 8.38087) and receives water from KagoroTsonje Mountains that flows through gidanwaya community; this water is the main source of water for both irrigation and other domestic activities, which also leached into groundwater.

Station 3. This is located at Gidan waya community, where all rivers and streams flow through and impacted by mining contaminated water. (9.28085, 8.22573).

Station 4. This is located at HayinGada where community source of water is well water and streams.(9.46099, 8.37862).

Station 5. This was located at Tudun wada community (9.4311469, 8.3702345) before Godogodo community, there major source of water is the stream and few wells.

Station 6. This was located before Godogodo community (9.53905, 8.385953) There are more mining activities within the community and there water sources are majorly dug wells.

Collection of Water Samples

Groundwater was sampled twice monthly, April to September, 2024; between 8:00am-10:00am. At each mining site one-litre pre-washed polythene bottles were immersed 20-20cm below the surface and corked under water to reduce air bubbles. Samples were placed in a cold flask and transported to the laboratory for analysis following APHA (2005)procedures.

Collection of sediments samples

Sediments from all sampling stations were collected twice monthly, April to September 2024 with Van veen grab (15cm by 15cm). Three grab samples were collected at each station and emptied into clean polyethene bags and labeled and were transported to the laboratory for analysis following APHA (2005) procedures.

Determination of Physico-chemical Parameters

The physico-chemical parameters determined were: temperature, transparency, pH, conductivity, total dissolved solids TDS, dissolved oxygen, salinity and trace metals which included, zinc, lead, cadmium and copper; nutrients included nitrates and phosphate. The pH, salinity, TDS and conductivity were determined using buffered electronic meter; EUTECH instruments (OAKTON Multi-Parameter PCSTestr™35). Transparency was measured using a caliberatedsecchi disc.

Dissolved oxygen concentration was determined using portable DO Meter (LUTRON Dissolved Oxygen Meter. PDO-520) values were recorded in mg/L. Temperature was measured in the field using a mercury-in-glass thermometer with 0.1 ^{0}C division on a Celsius scale. Nitrate and phosphates in the water sample was determined using Spectrophotometric screening according to APHA (2005).

Heavy Metals Analysis

Water and sediment samples collected, digested and analysed for Heavy metals, cadmium, copper, lead and zinc, according to methods in APHA (2005) using Atomic Absorption Spectrophotometer (AAS) (Buck model 210-VCP).

Statistical Analysis

Data were subjected to descriptive statistics, using SPSS v23.Two-way ANOVA was used to analyze for variations in the different sampling stations and different sampling months. Post hoc comparisons were carried out using Duncan's Multiple Range Test (DMRT) was used to measure the similarities of the sampling stations and sampling months. Pearson correlation coefficient was used to determine the interdependence of the physico-chemical.Principal component analysis was used to determine the most significant component affecting the groundwater.

RESULTS

Physico-chemical Parameters obtained from Water and Sediments Samples

Results recorded during the period of study from April to September 2024 of physico-chemical parameters, were presented. The results were treated station by station and monthly by monthly comparatively and table 1 show the mean values standard deviation of physic-chemical parameters observed during the study. Results obtained showed that air temperature ranged from 23-32.30 ^{o}C, highest value was recorded in the month of April (31.9 $\pm$0.53 °C) while the lowest monthly value was recorded in August (23.7 $\pm$0.47 °C), water temperature ranged from 25.30-32.10 ^{o}C, the maximum value was recorded in themonth of April (31.9 $\pm$0.53 °C) and the minimum value recorded in the month of August (25.5 $\pm$0.0 5°C), pH was from 6.34-8.57, the maximum value was recorded in the month of April (8.22$\pm$0.22) while the lowest in the month of July (6.60$\pm$0.16), salinity was from 122 to 150.5 ppm, the maximum value was recorded in the month of April (150.5$\pm$1.76 ppm) and the lowest values was recorded in the month of July(122 $\pm$2.65 ppm), conductivity was from 254.4 to 312.67 µmhos/cm the

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maximum conductivity was recorded in the month of May (312.67 ±2.64 µmhos/cm), lowest value was recorded in the month of July (254.4 ±7.38 µmhos/cm), total dissolved solids ranged from 205.05 to 219.33 ppm, the highest value was recorded in the month of April (219.33±1.75 ppm) while the lowest value was recorded in the month of August (205.08 ±3.65 ppm), dissolved oxygen was from 3.50-14.20 mg/L the highest DO was recorded in the month of June(11.04 ±2.72 mg/L), and the lowest was recorded in the month of April (3.59 ±0.08 mg/L), transparency was from 25.30-70.10 cm, the highest was recorded in the month of June (49.11±2.25 cm), and the lowest was recorded in the month of September (26.43±0.88 cm), nitrates in surface water ranged from 0.06 to 8.12 mg/L, the maximum value was recorded in the month of April (8.12 mg/L) while the lowest value was recorded in the month of July (0.06 mg/L), phosphate ranged from 0.22 to 0.35 mg/L. There was significant difference ($p<0.05$) in the monthly values of physico-chemical parameters. Transparency was negatively correlated with total dissolved solids (r= -.76) (Table 2). Copper in surface water ranged from 0.002 to 0.04 mg/L, zinc values in surface water ranged from 0.025 to 0.30 mg/L, lead and cadmium in surface water were below detectable level of 0.0000 mg/L, Cadmium was also found to be below detectable limit with values of 0.0000 mg/kg in sediment collected at different stations, while zinc has the highest value (0.16 mg/L) among heavy metals analysed.There was no significant difference ($p>0.05$) along the stations. Figure 1-14 shows the spatial and temporal variation of physicochemical parameters in during the Study period.

Table 1. Summary of physicochemical parameters in groundwater around mining sites in Jema'a Local Government Area, during the study period

Variable	Min	Max	Mean	StdDev
Air temperature (°C)	23.00	32.30	26.74	2.82
Water temp (°C)	25.30	32.10	27.71	1.85
pH	6.340	8.57	7.08	0.61
Salinity (ppm)	119.00	153.00	138.05	8.96
Conductivity (µmhoS/cm)	244.00	315.00	287.73	21.34
TDS (ppm)	175.00	228.00	205.58	15.54
DO (mg/ L)	3.50	14.20	6.76	2.72
Transparency (cm)	25.30	70.1	42.75	13.64
Nitrate (mg/L)	0.03	10.58	1.49	3.07
Phosphate (mg/L)	0.16	0.42	0.32	0.07
Cadmium (mgL)	0.000	0.000	0.000	0.000
Copper (mg/L)	0.000	0.060	0.010	0.020
Lead (mg/L)	0.000	0.000	0.000	0.000
Zinc (mg/L)	0.01	1.14	0.08	0.19

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Vol. 9, No. 3

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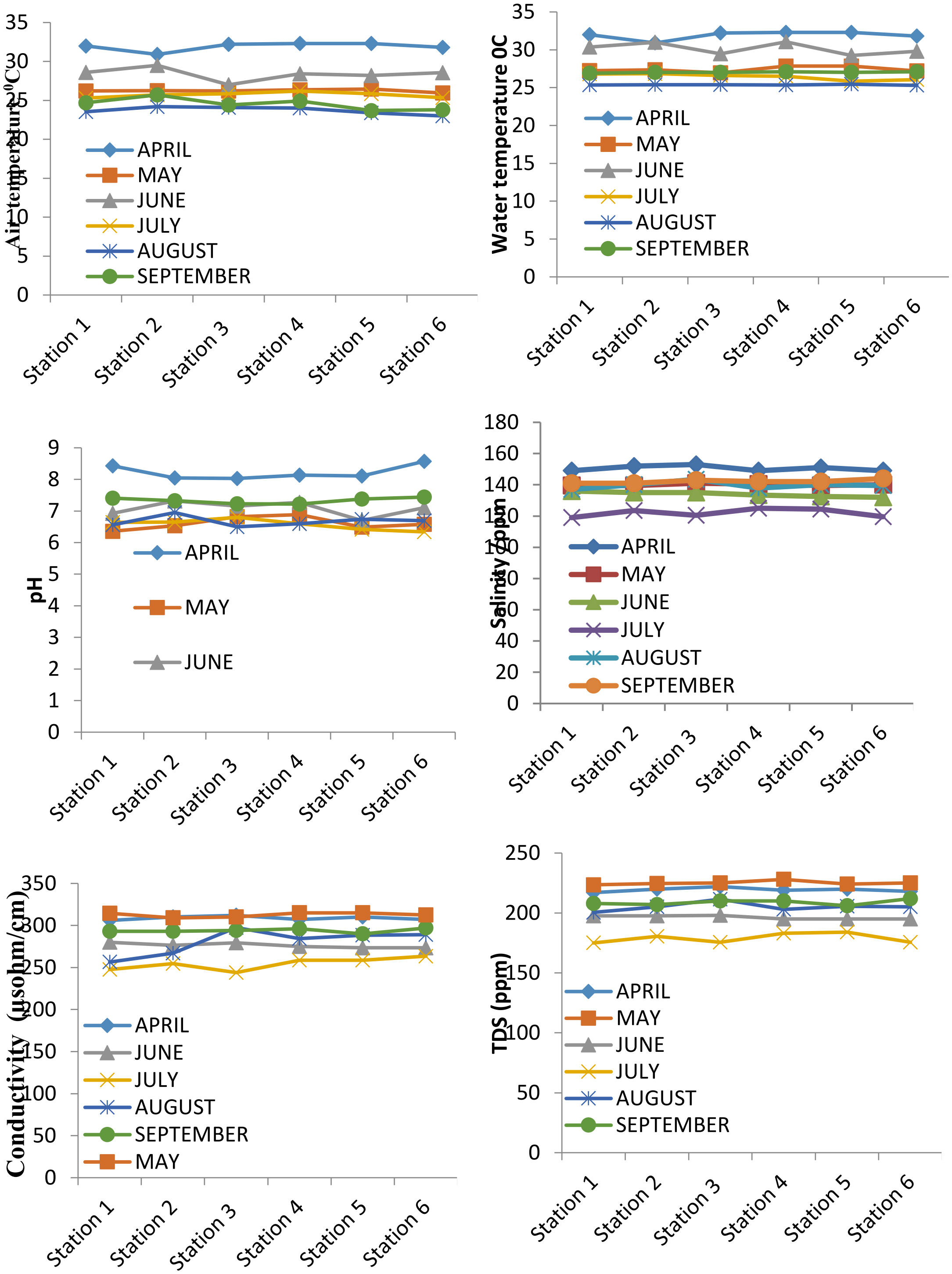
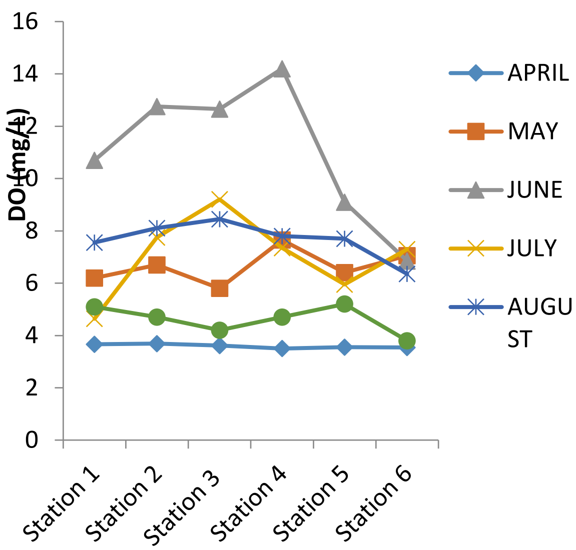
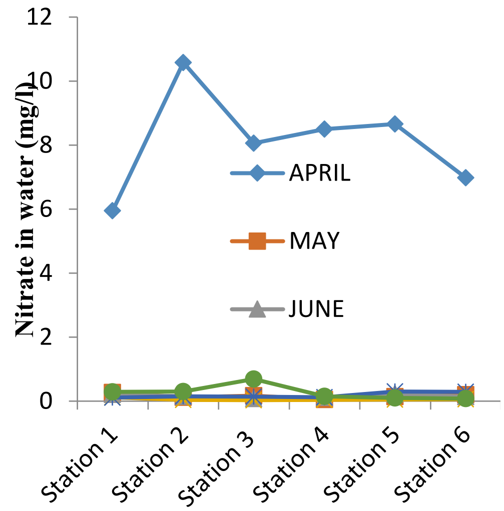


Fig 1-6Spatio-temporal variation of physico-chemical parameters in groundwater around mining sites in Jema'a L.G.A during the Study period

Vol. 9, No. 3
Journal of Health, Metabolism and Nutrition Studies





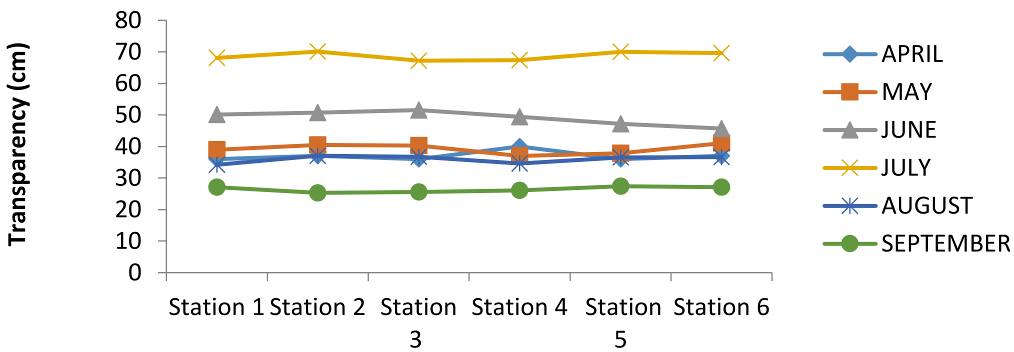
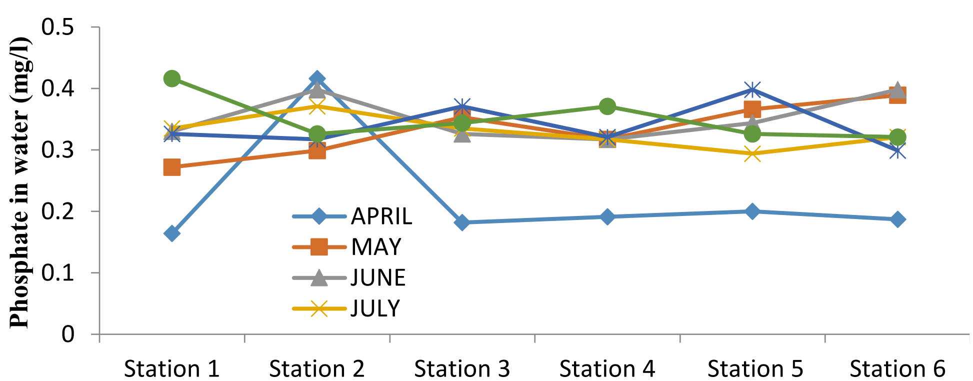
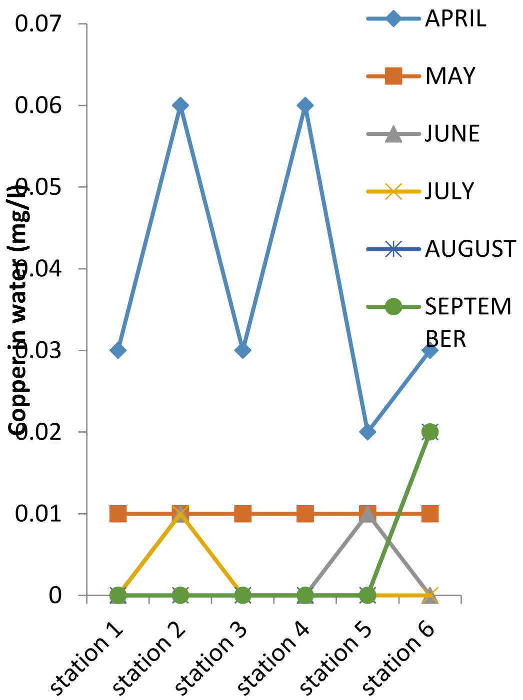


Fig 7-9 Spatio-temporal variation of physico-chemical parameters in groundwater around mining sites in Jema'a L.G.A during the Study period





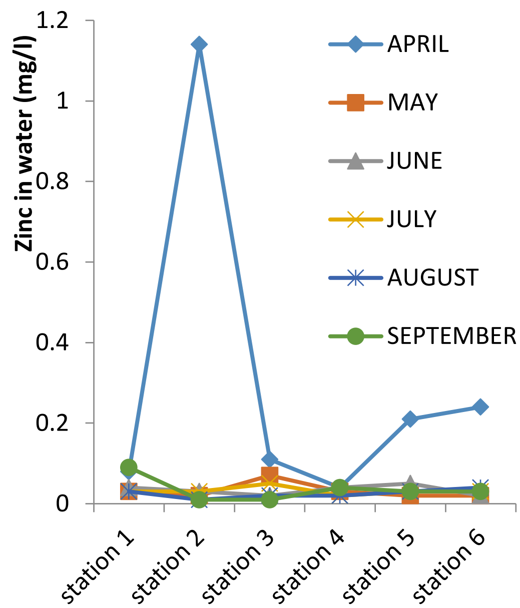


Fig 10-12Spatio-temporal variation of physico-chemical parameters in groundwater around mining sites in Jema'a L.G.A during the Study period

Health Risk Assessment

Table 2. Summary of Health risk assessment parameters compared with WHO and other sources

Parameter	Unit	Range	WHO Limits	Associated health risk	Sources for Comparison
Air Temperature	°C	23.0 - 32.3	No direct WHO guideline for air temperature	Elevated air temperatures can exacerbate eutrophication and affect the solubility of oxygen.	Yariv et al. (2020); WHO (2003).
Water Temperature	°C	25.3 - 32.1	No direct WHO guideline for water temperature	Elevated temperatures can lower DO levels, promote harmful algae blooms, and affect aquatic life.	Yariv et al. (2020); WHO (2006).
pH	-	6.34 - 8.57	6.5 - 8.5	No health risk; values within safe range.	Jenkins et al. (2021); WHO (2006).
Salinity	ppm	119 - 153	No direct WHO guideline; salinity <500 ppm for	No health risk to humans; can impact aquatic life if salinity increases.	García et al. (2019); WHO (2011).

Parameter	Unit	Range	WHO Limits	Associated health risk	Sources for Comparison
			freshwater organisms		
Conductivity	µmhoS/cm	244 - 315	No direct WHO guideline for conductivity	No immediate health risk; high conductivity indicates potential pollution.	Lima et al. (2017); WHO (2011).
TDS	ppm	175 - 228	<1,000 mg/L for drinking water	Safe for drinking water; potential impacts on taste.	Lima et al. (2017); WHO (2011).
Dissolved Oxygen (DO)	mg/L	3.5 - 14.2	>5 mg/L for aquatic life	Low DO (<5 mg/L) indicates pollution or eutrophication, leading to health risks for aquatic life.	Bishop et al. (2018); WHO (2006).
Transparency	cm	25.3 - 70.1	No direct WHO guideline for transparency	Low transparency could indicate turbidity and poor water quality, affecting aquatic ecosystems.	Yariv et al. (2020); WHO (2003).
Nitrate	mg/L	0.03 - 10.58	<50 mg/L for drinking water	Safe for drinking, but high levels contribute to eutrophication.	Jenkins et al. (2021); WHO (2006).
Phosphate	mg/L	0.16 - 0.42	No direct WHO guideline for phosphates in water	High phosphate levels lead to eutrophication and oxygen depletion, impacting aquatic life.	García et al. (2019); WHO (2006).
Cadmium (Cd)	mg/L	0.000 - 0.000	0.003 mg/L for drinking water	Not detected (safe). Potential health risk if levels increase.	Hassaan et al. (2019); WHO (2011).
Copper (Cu)	mg/L	0 - 0.06	2.0 mg/L for drinking water	Low levels are safe; copper is a health risk at high concentrations.	Hassaan et al. (2019); WHO (2011).
Lead (Pb)	mg/L	0.000 - 0.000	0.01 mg/L for drinking water	Not detected (safe). Potential health risk if levels increase.	Hassaan et al. (2019); WHO (2011).
Zinc (Zn)	mg/L	0.01 - 1.14	5.0 mg/L for drinking water	No immediate health risk; elevated levels can cause gastrointestinal issues.	Hassaan et al. (2019); WHO (2011).

***table was generated from the data set in table 1**

DISCUSSION

The high value of air temperature in April could be attributed to dry season with increased Sun intensity and it's decreased in August could be as a result of increase in cloud cover and rainfall consistent with similar studies (Oyibio-Olaifa et al., 2024;Ojo, 2023) although elevated air temperatures can increase eutrophication and affect the solubility of oxygen (Yariv et al., (2020). The surface water temperature of this region show almost same pattern with air temperature, following slight changes in the air temperature at all stations, this was also evident in the correlation coefficient showing high degree of association between the air temperature ($p<0.05$). From the analysis of variance, Water temperature shows positive correlation with air temperature, pH and nitrate.

The surface water pH of the study area was tending towards alkalinity (6.60 to 8.22) but remain within WHO limit. In this study the maximum value was recorded in the month of April which may not be unconnected with high photosynthesis as suggested by Ayoade&Nierzwicki-Bauer (2020) who noted in earlier studies. The pH values in the present study did not exceed the suitable limit for good water quality;this suggests that groundwater is safe and poses no immediate health risk with respect to pH (Jenkins et al., 2021).

The highest salinity in April and the lowest in July showed gradual decrease with increase in water level resulting in dilution(Olaoye et al., 2012).

The conductivity values of study area falls within the intermediate limits and also within acceptable limit (50-600 μmhoS/cm) of WHO; indicating moderate ionic strength typical groundwater (Ojo, 2023) in mining areas.

The highest DO recorded in June when temperature was low showed that high DO is related to low temperature (Eyibio-Olaifa et al., 2024); the lower DO seen in April across all sampling point can be due to increased temperature.

Water clarity was reduced by suspended sediments which could be as a result of mining activities (Ojo, 2023). The highest transparency recorded in June, and the lowest in September may be as a result of increase in turbulence of water in the run-off from mining sites.

Nutrients in the study (Nitrate and Phosphate)exhibit seasonal variability. Nitrates were high in April and decline in June, possibly due to increased rainfall and dilution although elevated nitrate levels can be toxic to fish above 10mg/L (NESREA, 2011), inthis study Nitrates is still within acceptable limit.Phosphate values did not show any trend; though highest value was recorded in June and the lowest was recorded in April. But remained relatively stable and within WHO guidelines.

Trace metals in groundwater were generally low. Copper (Cu) concentration (0.002-0.04mg/L) and Zinc (Zn) concentration (0.025-0.30mg/L) Lead (Pb) and Cadmium (Cd) were below detectable limits, suggesting limited contamination from these highly toxic metals. Even though they do not pose any immediate health risk monitoring is required as prolonged exposure may result in bioaccumulation in aquatic organisms, and crops irrigated with contaminated mining water (Alsafran et al., 2021)

Conclusion

This study signifies that groundwater near mining sites in Jema'a LGA shows early signs of pollution, particularly the Physico-chemical parameters of surface water varied from month to month and across the stations which showed how water quality parameters change. It is well documented that aquatic bodies are under threat from anthropogenic stress which was clearly seen in the results. Although most measured parameters were within WHO and NESREA guidelines, presence of trace metals and the strong influence of mining related runoff highlight the need for consistent monitoring. If the mining activities continued without intervention heavy metals levels may increase posing grievous risk to local food security and public health.

Recommendations

From this study the following are recommended

1. Frequent monitoring of water quality should be maintained within the mining sites to track changes and heavy metals presence.
2. Further studies should be carried out to assess bioaccumulation in plants especially vegetables grown with irrigation water gotten from mining sources.

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Data availability statement.

The data that supported the findings can be made available upon reasonable request.

Conflicts of Interest: The authors declared that they have no known competing financial interest or personal relationships that could have appeared to influence the work reported in this paper.

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