FEDERAL UNIVERSITY WUKARI INTERNATIONAL JOURNAL OF BIOSCIENCES (FUWIJOB)
pISSN: 3121-9799, eISSN: 3121-973x; Volume 2, No. 2, June, 2026
https://fuwijob.com.ng

Assessment of Heavy metals and Physicochemical Parameters of Water found in Maiganga Mining Site Gombe Nigeria.

[1,2]Umar, A. M, [2]Umar, A. M, [2]Saidu, H, [1]Muhammad, A. I. & [1]Abubakar, B.

[1]Department of Science Laboratory Technology, Federal Polytechnic Kaltungo, Gombe, Nigeria
[2]Department of Biological Science, Gombe State University Gombe, Gombe Nigeria

***Corresponding author**: adamci1027@gmail.com

ABSTRACT
Industrial coal mining at the Maiganga site in Gombe State, Nigeria, poses severe ecological risks due to the alteration of the local landscape and the generation of toxic Acid Mine Drainage (AMD). This study presents an integrated environmental evaluation of the Maiganga coalmine ecosystem concurrently investigating the heavy metal contamination and seasonal hydrogeochemical cycles of its water system. Six spatial water sampling points (W1–W6) within the mining zone were analyzed for ten heavy metals using Atomic Absorption Spectrophotometer (AAS), while key physical and chemical water quality parameters were monitored monthly over a six-month seasonal window (May to October). Hydrogeochemical analysis revealed extreme heavy metal enrichment exceeding World Health Organization (WHO) permissible drinking water limits across all water points. Notable pollution hotspots included W2 for Nickel (259.67mg/kg) and W6 as a severe multi-metal epicenter tracking peak concentrations of Arsenic (10.03 mg/kg), Lead (5.76 mg/kg), and Iron (53.43 mg/kg). Longitudinal physical tracking confirmed active AMD initiation with a significant drop in pH during peak rainfall (July: 5.84) followed by a distinct late-monsoon "flushing effect" in October, which drove dramatic spikes in Electrical Conductivity, Total Dissolved Solids and Total Suspended Solids. The aqueous matrices within the Maiganga mining area are heavily compromised, seasonal monsoon retreats exacerbate dissolved mineral loads, and the water is completely unfit for community domestic or agricultural use.

Keywords: Mining, heavy metals, water, physicochemical and Assessment

INTRODUCTION
The extraction of coal remains a primary energy source globally, yet it poses severe environmental challenges, particularly the release of toxic heavy metals into surrounding ecosystems (Burachevskaya *et al*., 2021). In Gombe State, Nigeria, the Maiganga coal mining site represents a significant industrial hub where intensive extraction activities have profoundly altered the local landscape. Recent spatial mapping suggests the study area covers approximately 14.48 km² emphasizing the vast geographic footprint of its potential environmental impact (Aluwang *et al*., 2024).

When coal seams and their associated mineral overburdens are cracked open and exposed to atmospheric oxygen and seasonal precipitation, sulfide minerals principally pyrite undergo rapid chemical weathering (Adebayo *et al.,* 2021). This oxidation process generates sulfuric acid, giving rise to Acid Mine Drainage (AMD) (Nnabo *et al*., 2023). The resulting acidic leachate aggressively dissolves and mobilizes a suite of highly toxic, non-biodegradable heavy metals and metalloids into nearby aquatic channels and groundwater aquifers (El Hosry *et al*., 2023). Elements such as Nickel (Ni), Cadmium (Cd), Lead (Pb), and Arsenic (As) persist indefinitely in the hydrosphere, threatening local communities who rely on these water resources for domestic, livestock, and agricultural purposes (Yasmin *et al.*, 2022).

The severity of aqueous pollution in mining environments is rarely static; it is heavily dictated by seasonal hydrogeochemical cycles (Tepanosyan *et al.*, 2021). In the Guinea Savannah zones of Northern Nigeria, alternating wet and dry seasons drive a highly dynamic aquatic profile (Wasiu *et al.*, 2022). Complex fluctuations in water quality parameters—such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and nutrient concentrations (nitrates and phosphates)—directly control how these heavy metals dissolve, precipitate, or travel through the water table (Li *et al.*, 2021).

While extensive research has mapped the structural degradation of landscapes in Northern Nigeria, there remains a critical data gap regarding the exact hydrogeochemical footprint of the Maiganga operations. Understanding how seasonal monsoon cycles influence both physical water parameters and toxic metal loads is essential for designing effective remediation programs (Ande *et al.*, 2021). Therefore, this study aims to comprehensively evaluate the concentrations of ten major heavy metals (Cd, Cr, Fe, As, Cu, Co, Mn, Zn, Ni and Pb) across different water points (W1–W6) within the Maiganga mining area, comparing them directly against international World Health Organization (WHO) permissible limits. Furthermore, this research monitors monthly shifts in key physical and chemical parameters over a six-month window (May to October) to isolate the seasonal "flushing effects" driving mine-induced water pollution. Ultimately, these insights seek to provide an empirical foundation for a sustainable aquatic reclamation and public health protection framework in Gombe State.

MATERIALS AND METHODS

Study Area

The study was conducted in Maiganga coal mining site in kumo, Gombe State. The site is located at kumo of Akko local government in Gombe state. The study area is bounded by the following coordinates; Latitudes 11°07'46.44''E – 11°10'11.72''E and Longitude 9°57'57.85''N – 9°59'41.08''N with an area coverage of 14.48 km2 (Aluwang *et al.*, 2024**).**

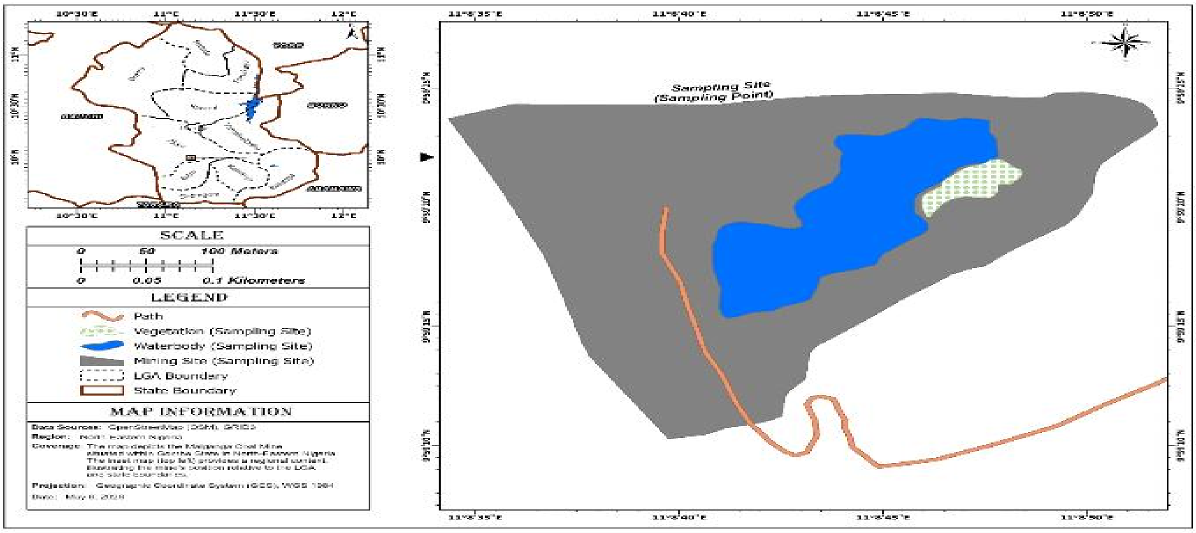

Fig 1: Map of Maiganga coalmine showing sample site (digitization from google earth pro Arc gis 10.3)

Collection of Water Sample

In this study six water samples were collected using one litters plastic jars within the mining site. Prior to filling the jars, each sampling bottle was washed thrice with clean water before sampling as described by Yasmin *et al.* (2022). The samples were promptly moved to Biochemistry Laboratory for Analysis.

Water Sample Preparation for Heavy Metal Analysis

Heavy metal analysis was conducted using FS240AA Atomic Absorption Spectrophotometer. The samples were thoroughly mixed by shaking, and 100ml of it was transferred into a glass beaker of 250 ml, to which 5ml of concentrated nitric acid was added and heated to boil till the volume reduced to about 15-20ml. Aliquot 5ml of concentrated nitric acid was added periodically until all the residues were completely dissolved. The mixture was cooled, transferred and made up to 100 ml using metal free distilled water. The sample was aspirated into the oxidising air-acetylene flame. When the aqhueous sample aspirated, the sensitivity for 1% absorption was observed as described by El Hosry *et al.* (2023). Ten (10) major toxic heavy metals (cadmium (Cd), chromium (Cr), iron (Fe), arsenic (As) lead (Pb), nickel (Ni), zinc (Zn), Manganes (Mn), Cobalt (Co) and Cupper (Cu)) in the samples were determined with BUCK SCIENTIFIC 210/211VGP Atomic Absorption Spectrophotometer (AAS) under standard method as described by Adetunji *et al.* (2022).

Assessment of Physicochemical Properties of the Water Samples

The collected water samples were analysed according to the method prescribed by the American Public Health Association, APHA (Nong *et al.*, 2019). The pH and electrical conductivity (µs/cm) of the samples were measured in situ using pH meter and conductivity meter respectively. Total dissolved solvent (TDS) was determined using APHA. Total Hardness (TH) was conducted by EDTA titrimetric method. Chloride (Cl-) was estimated using the Argentometric method. Nitrate (NO3 -), Phosphate iron (PO4) and Sulphate iron (SO4) was estimated using the procedures given by APHA (Aluwong *et al.* 2024).

Data Analysis

All analytical measurements were performed in triplicate. Data were expressed as Mean ± Standard Error of mean (SEM). Analysis of Variance (ANOVA) was performed, followed by a post-hoc test at a 95% confidence interval ($p < 0.05$).

RESULTS

Heavy Metals Concentration in the Water of Maiganga Mining Site

Concentration of ten heavy metals (Cd, Cr, Fe, As, Cu, Co, Mn, Zn, Ni and Pb) in water of Maiganga coal mine was examined, which indicates a significant difference ($P<0.005$) between the heavy metals and Well water. The heavy metals Concentrations in the mining site is presented in Table 1. The result showed that highest Arsenic concentration was recorded in W6 (10.03), W5 (2.76), while W4 (0.39) has the lowest Arsenic concentration. Cadmium (Cd) concentration level becomes higher at W6 (14.72) while at W3 (0.12) indicate lowest concentration among the Samples. Lead (Pb) indicate high concentration in W6 (5.76) and indicate low concentration in in W3 (0.17) among the samples. W2 showed high concentration of Nickel (259.67) than any other metal among the samples. Cupper (Cu) was found to be higher in W3 (4.57) and lower concentration in W2 (0.40). Iron showed high concentration in W6 (53.43). in all the samples cobalt indicate low concentration among all the heavy metals. Zinc indicates high concentration in W3 (99.65) and lower in W2 (25.44) among the samples. Manganese indicates high concentration in W3 (1.21) and lower (1.21) in W5.

Table 1: Heavy metals concentration in the Water of Maiganga Mining Site

Samples	As (mg/L)	Cd (mg/L)	Pb (mg/L)	Ni (mg/L)	Cu (mg/L)	Fe (mg/L)	Co (mg/L)	Cr (mg/L)	Zn (mg/L)	Mn (mg/L)
W1	1.98±0.00^{c}	5.05±0.00^{c}	0.96±0.00^{c}	39.56±0.00^{d}	1.85±0.00^{d}	16.19±0.00^{e}	0.15±0.00^{d}	2.63±0.00^{c}	57.78±0.00^{c}	4.40±0.00^{b}
W2	1.13±0.00^{d}	0.30±0.00^{e}	0.52±0.00^{d}	259.67±0.00^{a}	0.40±0.00^{f}	8.37±0.00^{f}	0.12±0.00^{e}	0.84±0.00^{f}	25.44±0.00^{f}	1.90±0.00^{e}
W3	0.49±0.00^{e}	0.12±0.00^{f}	0.17±0.00^{f}	65.21±0.00^{c}	4.57±0.00^{a}	21.68±0.00^{c}	0.58±0.00^{b}	3.93±0.00^{b}	99.65±0.00^{a}	4.79±0.00^{a}
W4	0.39±0.00^{f}	2.47±0.00^{d}	0.50±0.00^{e}	88.36±0.00^{b}	1.05±0.00^{e}	20.10±0.00^{d}	0.45±0.00^{c}	1.03±0.00^{e}	51.77±0.00^{d}	3.47±0.00^{c}
W5	2.76±0.00^{b}	5.50±0.00^{b}	3.93±0.00^{b}	18.45±0.01^{f}	2.96±0.00^{c}	46.37±0.00^{b}	0.10±0.00^{f}	2.51±0.00^{d}	37.88±0.00^{e}	1.21±0.00^{f}
W6	10.03±0.00^{a}	14.72±0.00^{a}	5.76±0.00^{a}	24.17±0.00^{e}	4.53±0.01^{b}	53.43±0.00^{a}	3.59±0.00^{a}	10.25±0.00^{a}	58.40±0.01^{b}	2.06±0.00^{d}

W1 to W6 = Water samples of different location within the mining area. Mean ± standard error of mean. Values with the same super script in the same Colum indicate no significant difference.

Comparison between concentrations of heavy metals of Maiganga Coalmine Water with permissible limit.

Comparison between concentrations of heavy metals of mining site water with permissible limit is presented in Table 2. The cadmium (Cd) concentrations, range 0.12 – 14.72 mg/kg in the samples indicate higher concentration than permissible limit of 0.003 mg/kg. Chromium (Cr) concentration ranges from 0.84 – 10.25 mg/kg in the samples shown higher than the permissible limit of 0.05 mg/kg. Iron (Fe) ranging from 8.37 – 53.43 mg/kg shown higher concentration than the permissible limit of 0.3 mg/kg. Arsenic (As) and lead (Pb) ranging from 0.39 – 10.03 and 0.09 – 5.76 mg/kg respectively shown significantly higher concentration than the permissible limit of 0.01 mg/kg. Nickel (Ni) and Cobalt (Co) among the heavy metals range 18.45 – 259.67 and 0.10 – 3.59 mg/kg respectively also shown higher concentration than the permissible limit of 0.07mg/kg. Among the samples Zinc (Zn) and Manganese (Mn) ranges 37.88 – 99.65 and 1.21 – 4.79 shown higher than the permissible limit of 5 and 0.08 respectively.

Table 2: Comparison between concentrations of heavy metals of Maiganga Mining site Water with permissible limit.

ELEMENTS		SAMPLES (Water)	CONCENTRATION (Mg/Kg)	WHO PERMISSIBLE LIMIT (mg/kg)
		W 1	5.05	
1	**Cd**	W 2	0.30	**0.003**
		W 3	0.12	
		W 4	2.47	
		W 5	5.50	
		W 6	14.72	

2	Cr	W 1	2.64	0.050
		W 2	0.84	
		W 3	3.93	
		W 4	1.03	
		W 5	2.51	
		W 6	10.25	
3	Fe	W 1	16.19	0.300
		W 2	8.37	
		W 3	21.68	
		W 4	20.10	
		W 5	46.37	
		W 6	53.43	
4	As	W 1	1.98	0.010
		W 2	1.13	
		W 3	0.49	
		W 4	0.39	
		W 5	2.76	
		W 6	10.03	
5	Pb	W 1	0.09	0.010
		W 2	0.52	
		W 3	0.17	
		W 4	0.50	
		W 5	3.93	
		W 6	5.76	

ELEMENTS		SAMPLES (Water)	CONCENTRATION (Mg/Kg)	WHO PERMISSIBLE LIMIT (mg/kg)
6	Ni	W 1	39.56	0.07
		W 2	259.67	
		W 3	65.21	
		W 4	88.36	
		W 5	18.45	
		W 6	24.17	
7	Cu	W 1	1.85	2.00
		W 2	0.40	
		W 3	4.57	
		W 4	1.05	
		W 5	2.96	
		W 6	4.53	
8	Co	W 1	0.15	0.07
		W 2	0.12	
		W 3	0.58	
		W 4	0.45	
		W 5	0.10	
		W 6	3.59	

9	**Zn**	W 1	57.78	**5.00**
		W 2	25.44	
		W 3	99.65	
		W 4	51.77	
		W 5	37.88	
		W 6	58.40	
10	**Mn**	W 1	4.40	**0.08**
		W 2	1.90	
		W 3	4.79	
		W 4	3.47	
		W 5	1.21	
		W 6	2.06	

Physicochemical parameters of Maiganga coalmine water for Six Months.
Physical and Chemical parameters of Maiganga coalmine water are presented in Table 3 and 4 respectively. The water quality analysis monitors five physical parameters and four chemical parameters monthly from May to October. The water PH was near-neutral in May (6.97) and August (6.94), but showed a significant shift toward acidity in July (5.84) and October (6.03). Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Total Hardness (TH) decreased from May to reach their lowest values in July (EC: 375.00 TDS: 183.67 TH: 207.67). Subsequently, concentrations rose significantly, culminating in a sharp, statistically distinct peak in October (EC: 1158.00 TDS: 575.00 TH: 536.67). The TSS showed a highly significant increase over the six-month period. It rose steadily from 563.00 in May to its highest concentration of 2275.30 in October (Table 3). Nitrate concentrations were highest in August (142.30), peaking after the initial drop in May and June. The lowest concentration was observed in July (57.78). Phosphate levels showed extreme variability. It was highest in October (66.10) and lowest in July (1.66), with a sharp decrease followed by a steep increase from August to October. Sulfate showed a highly dynamic trend, peaking in July (89.71) and recording its lowest concentration in June (9.28). Chloride concentrations decreased from May to July (52.76) but then increased steadily, culminating in the highest recorded value in October (268.02) as described in Table 4.

Table 3: Physical parameters of Maiganga coalmine water for six months.

Months	pH	E.C (µS/cm)	T.D.S (mg/dm³)	T.S.S (mg/dm³)	Totaal Hardness (mg/dm³)
May	6.97±0.00^{a}	613.00±4.36^{b}	306.00±1.73^{b}	563.00±7.55^{f}	276.00±5.20^{b}
June	6.42±0.01^{b}	414.00±1.73$_{e}$	198.00±1.73^{e}	774.00±5.00^{e}	217.67±2.40^{d}
July	5.84±0.01^{e}	375.00±3.46^{f}	183.67±1.20^{f}	1115.30±1.20^{d}	207.67±1.86^{d}
August	6.94±0.00^{a}	561.00±3.46^{c}	281.00±1.00^{b}	1417.70±1.45^{c}	277.00±1.53^{b}
September	6.37±0.00^{c}	433.00±3.61^{d}	215.00±1.00^{d}	1742.30±5.04^{b}	247.33±2.19^{c}
October	6.03±0.01^{d}	1158.00±1.73^{a}	575.00±1.00^{a}	2275.30±1.86^{a}	536.67±1.76^{a}
P≤ 0.005	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**

EC = Electrical conductivity, TDS= Total dissolved solids, TSS= Total suspended solids, TH= Total hardness. Mean ± standard error of mean. Values with the same super script in the same Colum indicate no significant difference.

Table 4: Chemical parameters of Maiganga coalmine water for six months.

Months	NO_3	PO_4	SO_4	Cl^-
May	108.53±0.32^c	46.71±0.23^b	37.76±0.08^c	162.63±0.91^c
June	81.10±0.18^d	25.40±0.05^d	9.28±0.08^f	86.83±0.40^e
July	57.78±0.55^e	1.66±0.06^f	89.71±0.09^a	52.76±0.89^f
August	142.30±0.40^a	3.85±0.05^e	46.18±0.31^b	107.68±0.48^d
September	78.91±0.40^d	42.31±0.13^c	31.15±0.11^e	243.50±0.92^b
October	113.20±0.74^b	66.10±0.10^a	34.55±0.16^d	268.02±0.48^a
P≤0.05	**0.000**	**0.000**	**0.000**	**0.000**

NO_3 = Nitrate iron, PO_4 = Phosphate, SO_4 = Sulfate iron and Cl^- = Chloride ion. Mean ± standard error of mean. Values with the same super script in the same Colum indicate no significant difference.

DISCUSSION

The assessment of water samples from the Maiganga coal mine reveals a profile of extreme heavy metal enrichment. The statistical significance ($P < 0.005$) between the mining site water and the control well water underscores the profound impact of coal mining activities on the local hydrogeochemical environment. These findings suggest that the water is unfit for domestic or agricultural use without extensive remediation. The most alarming result is the concentration of Nickel (Ni) in sample W2 (259.67 mg/L). This value is exponentially higher than the WHO permissible limit of 0.07 mg/L. The concentration is drastically higher than levels recorded in the Witbank Coalfield, South Africa, where Ndlovu *et al.* (2023) reported Ni levels averaging between 0.5 and 5.0 mg/kg. The extreme values in Maiganga suggest the presence of highly soluble nickeliferous minerals or a lack of natural neutralizing agents (like carbonates) in the Gombe Formation, allowing for unchecked metal mobilization. The peak Cd level of 14.72 mg/kg exceeds findings by Singh *et al.* (2022) in the Jharia Coalfield, India, where maximum Cd concentrations reached 0.85 mg/kg. Cadmium is highly toxic and mobile; its presence at these magnitudes indicates severe chemical weathering of the coal overburden. Sample W6 functions as a localized multi-metal hotspot, recording peak values for Arsenic (10.03 mg/kg), Lead (5.76 mg/kg), and Iron (53.43 mg/kg). The Arsenic concentration (10.03 mg/kg) is significantly higher than the 2.14 mg/kg reported by Zhang *et al.* (2024) in the Shanxi mining province, China. Lead levels (5.76 mg/kg) also surpass the 1.2 mg/kg threshold observed by Oluwatosin *et al.* (2023) in the Igun gold mining area of Southwest Nigeria. These findings suggest that Maiganga's coal seams may be enriched with arsenopyrite and galena, which oxidize rapidly upon exposure to air and water during mining. The Iron peak (53.43 mg/k) is a direct indicator of pyrite oxidation. This mirrors findings by Adebayo *et al.* (2021) in the Enugu coal mines, where high Fe was strongly correlated with low pH and high sulfate levels, confirming the presence of Acid Mine Drainage. The Zinc (99.65 mg/kg) observed at Maiganga is notably higher than the 15.4 mg/kg recorded by Kouakou *et al.* (2022) in Ivorian mining effluents. Zinc is often associated with sphalerite within coal deposits. Its high concentration in the aqueous phase suggests that W3 might be a site of active dissolution Cu (4.57 mg/kg) and Mn (1.21 mg/kg) are elevated relative to international standards, though Mn is relatively lower compared to the other metals. This matches the trend observed by Li *et al.* (2021) in Appalachian coal mine discharges, where Mn is often the most persistent metal but not necessarily the most concentrated. The physicochemical profile of the Maiganga coalmine water from May to October indicates a highly dynamic aquatic environment, strongly influenced by seasonal rainfall and the chemical weathering of coal-bearing strata. The shift from near-neutral (May: 6.97) to acidic (July: 5.84 and October: 6.03) suggests the onset of Acid Mine Drainage (AMD). This trend aligns with the findings of Ayuba and Lawal (2024) in the Kogi coal mines, where pH decreased during the rainy season as oxygenated rainwater reacted with exposed pyrite, flushing sulfuric acid into the water system. The lowest values in July followed by a sharp peak in October (EC: 1158.00 S/cm, TDS: 575.00 mg/L, TH: 536.67 mg/L) indicate a "flushing effect" where accumulated minerals are concentrated as the rainy season ends. Tepanosyan *et al.* (2021) observed a similar pattern in Armenian mining districts, where mineral dissolution increased significantly post-rainfall, leading to elevated salinity and hardness. The massive increase of T.S.S from 563.00 in May to 2275.30 in October is indicative of severe surface erosion. The result conforms with the result of Agboola *et al.* (2020) reported that TSS levels in coal-impacted waters in North-central Nigeria typically peak in October due to the transport of fine coal particles and silt from unstable overburden piles during the retreat of the monsoon rains. The peaked of Nitrate in August (142.30 mg/L) while Phosphate surged in October (66.10 mg/L) are often linked to runoff from nearby agricultural activities combined with the decomposition of organic material in the coal overburden. Wasiu *et al.* (2022) noted that Gombe mining regions often show nutrient spikes during peak runoff as nitrogenous compounds are leached from the soil into my pits. High sulphate levels coinciding with low pH (seen in July) are the "chemical signature" of pyrite oxidation. Nnabo *et al.* (2023) stated that in the Benue Trough coal deposits, sulphate ions are the primary byproduct of sulfuric acid formation, acting as a marker for mining-induced pollution. Chloride increases steadily to reach 268.02 mg/L in October is in agreement with the result of Fashola *et al.* (2020) who suggested that rising chloride levels in mine-impacted water often result from the weathering of shale layers associated with coal seams or the concentration of salts due to high evaporation rates following the rainy season.

CONCLUSSION

This study provides a detailed evaluation of heavy metal contamination and seasonal physicochemical dynamics in the water system of the Maiganga coal mining site in Akko Local Government Area, Gombe State. The data reveals a highly compromised aquatic environment directly affected by active coal mining and mineral weathering. The hydrogeochemical environment is highly enriched with toxic elements, showing extreme statistical variance. Every single evaluated metal across all six sampling points (W1–W6) exceeded the WHO permissible limits for drinking water. The water within the Maiganga coal mining area is severely contaminated and entirely unfit for drinking, domestic chores, or livestock watering without advanced treatment.

CONFLICTS OF INTEREST

I declare that there are no known competing financial Interests or personal relationships that could have appeared to influence the work reported in this paper

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