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Physico-chemical assessment of surface water from mining activities in Maiganga coal mine, Gombe state, Nigeria

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Abstract

Purpose. Surface water from mining activities may undergo various physico-chemical changes that can impact its quality and ecological health. This study conducted a comprehensive physico-chemical assessment of surface water affected by mining operations, with a particular emphasis on heavy metal content.

Methods. These parameters were chosen due to their importance as indicators of water quality and potential contamination. Water samples were collected from different locations within and around Maiganga Coal mine area and analyzed using standard laboratory techniques. The assessment included the measurement of physico-chemical parameters such as temperature, total dissolved solids and concentrations of heavy metals such as chromium, lead, manganese, cadmium and copper. Also, cations and anions such as calcium, magnesium, sodium, potassium, nitrate, chloride sulfate and fluoride that can impact water quality were considered.

Findings. The results of the physico-chemical assessment revealed substantial variations of chromium (0.00-0.03 mg/l), lead (0.00-0.05 mg/l), manganese (0.00-12.11 mg/l), cadmium (0.10-0.14 mg/l) and copper (0.00-1.02 mg/l) concentrations. Also, cations and anions such as calcium (0.00-1.13 mg/l), magnesium (11.90-30.07 mg/l), sodium (0.20-1.11 mg/l), potassium (0.10-0.66 mg/l), nitrate (3.90-4.78 mg/l), chloride (84.0-319.0 mg/l), sulphate (8.0-240.0 mg/l) and fluoride (0.00-0.89 mg/l) can impact water quality levels across the sampled surface water bodies.

Originality. Evidence of acid mine drainage, caused by mine effluents that are limited to surface water and do not reach groundwater, has been found through analysis of data from wells, ponds, and streams.

Practical implications. These variations obtained could be attributed to the discharge of acidic or alkaline substances associated with coal mining activities.

Keywords: *surface water, heavy metals, cations and anions, physico-chemical composition*

1. Introduction

Mining activities have been identified as a significant source of surface water pollution. The effluents from mining activities usually contain high levels of heavy metals, minerals and other toxic substances that can pose significant health risks to humans and aquatic life. Physico-chemical parameters are used to assess water quality and pollution levels in surface and groundwater. Due to mining activities, various factors have contributed to changes in the content of heavy metals in surface water. These factors include the discharge of acidic or alkaline mine water, leaching of heavy metals and minerals, erosion of mining wastes, and the introduction of chemicals used in mineral processing [1].

Schmidt, Wainwright, Faybishenko, Denham, and Eddy-Dilekuse [2] use the Kalman filter to monitor in-situ groundwater contamination. This study uses a real-time, in-situ monitoring system for groundwater contamination based on in-situ quantifiable water quality characteristics, including Specific Conductance (SC). Principal Component Analysis (PCA) is used for the first time in this framework to find correlations between concentrations of contaminants of interest and quantifiable variables present in the system. Based on the measurable factors, the developed approach allows the estimation of these pollutant concentrations according to the results obtained.

Due to their rising use in industrialized societies and their increasing presence in anthropogenic waste streams worldwide [3], trace elements are one significant class of pollutants found in wastewater. The behavior of these trace elements during wastewater treatment and their possible large-scale sources are still poorly understood, which raises questions about the potential environmental effects on receiving habitats. The results show that wastewater surveillance is useful for quantitatively examining the differences in emissions of anthropogenic and geogenic trace elements, and they also emphasize the importance of this approach in advancing our

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knowledge of the current status of contaminants in wastewater and sewage sludge, as well as their behavior after treatment.

Ande et al., [4] assessed the physicochemical parameters of water and soil samples in the vicinity of Owukpa Coal Mine, Benue State, Nigeria. The Anchimodo, Eyari, and control samples' water bodies were found to be acidic based on the results, which were below the W.H.O.-recommended level of 8.00. The measurements of other physicochemical characteristics in the water samples were typically far lower than the W.H.O.-established level. Concerned about the excessive acidity found in the water sample, the government and decision-makers ought to ensure that mining policies are current and implemented appropriately at the mining site.

Onydinma et al., [5] looked at the skin absorption, physico-chemical characteristics, distribution and contents of sixteen key PAHs, and incremental lifetime cancer risk through consumption in borehole waters near car workshops in Southeast Nigeria. Target hydrocarbons (HCs) are mostly thought to originate from pyrogenic sources, based on the diagnostic ratios. The carcinogenic risks estimated for adults and children were greater than the tolerable cancer risk set by the US Environmental Protection Agency (USEPA), and significantly higher for children. This suggests that children may be at risk for cancer from ingestion.

Singh et al., [6] demonstration demonstrates the usefulness of the contamination index in identifying the critical components of groundwater resource contamination as well as the rapidly affected areas. Many developed contamination indices, such as the HPI, MPI, and CD, have been utilized in the literature to assess the concentrations of ionic species and heavy metals in groundwater. An appropriate way for assessing the actual and potential groundwater contamination in an area is the contamination index methods. Thus, the goal of this work was to examine laboratory data about the physico-chemical characteristics of water samples that were taken from Maiganga Coal Mine.

India's primary mining operation is the extraction of coal. In India, open-pit mines produce the majority of the country's coal. Water is heavily contaminated with many dangerous chemicals as a result of rising human population, industry, and man-made activities [7]. A necessary component for reducing illness and enhancing quality of life is the availability of clean water. An analysis of the physico-chemical properties of water in an open-pit coal mine located in Chirimiri, District Koriya, Chhattisgarh, from January to December of 2013-2014 was conducted and it was discovered that while the quality of the water is generally good, there are several criteria that are marginally above the allowable limit, including turbidity, calcium, fluoride, and total hardness.

The impact of mining operations on the quality of subterranean water is examined in this research [8]. Five samples were acquired, the majority of which were from subterranean water sources. Physical, biological, and chemical parameters were used to analyze the acquired samples. The outcome demonstrates how mining operations have resulted in a high concentration of chemical elements, such as nitrate, chloride, phosphate, cyanide, fluoride, iron, manganese, etc., that are affecting water quality. Additionally, the concentration of E. Coli bacteria in the majority of boreholes, wells, and streams was shown by the bacteriological investigation of these water samples.

The heavy metal contamination levels in farming water from Maiganga Community in Akko local government area of Gombe state, Nigeria, are investigated in this study [9]. The community's ten farming locations provided water samples for the collection. These came from boreholes, wells (which contain groundwater), and open water. After being digested, the samples were checked for the presence of heavy metals (lead, cobalt, nickel, cadmium, copper, and chromium) using the Buck Scientific 205 Atomic Absorption Spectrophotometer. Based on the source and location of the collected water, there was no significant difference ($P < 0.05$) in the presence of Lead, Nickel, Cobalt, and Cadmium, according to the data. There was a high level of heavy metal contamination in the water samples collected from the different sources.

Wet and dry season water samples from several sampling locations within the Maiganga Coal Mine Area in Gombe State were analyzed for physicochemical characteristics and some heavy metal content [10]. Using conventional techniques and atomic absorption spectrophotometry, the physicochemical characteristics and the amounts of heavy metals were ascertained. We compared the acquired results with the water sample limitations established by the World Health Organization (WHO). Total Dissolve Solid (TDS), Pb, and Cd were over the maximum allowable values established by W.H.O., however pH, conductivity, and TSS were generally low.

To evaluate the possible effects on nearby water resources, surface water, and groundwater, mining water quality needs to be routinely monitored [11]. This research assessed the physicochemical, microbiological, and heavy metal content of nearby paddy field and drainage water as well as mining drainage water to gauge the level of contamination. The mine water had the following characteristics: pH, EC, DO, TDS, and salinity; they were measured in s/cm, 100-600 s/cm, 25-369 ppm, 9.00-1.10 ppm, and 0.02-0.29 ppt, respectively. The water tested positive for Pb, Ni, Zn, and Fe contamination. Human dermatological issues may result from elevated levels of free sulfur caused by the presence of numerous sulfate-reducing bacteria in water sources.

The Maiganga Coal Mine area has long been the site of mining operations. These operations have produced a large amount of mine waste, which has contaminated the area's surface and ground water supplies. The level of contamination and its effects on the local environment and socioeconomic well-being have not been thoroughly investigated. In order to evaluate the physico-chemical properties of surface water resulting from mining activities, this study compares the water quality in mining-affected areas with standards developed and approved by regulatory agencies that oversee the environment and public health.

1.1. Study area

Maiganga is located right after Kumo town, 8 km off the Gombe-Yola route. It has a surface area of roughly 48.16 km^2. The rainy season lasts for five to six months, with rainfall ranging from 850 to 1000 mm^3. Much of the year has comparatively high temperatures. Open grasslands, shrubs, and a few solitary trees make up the vegetation. Among the tree species found in the region are Mumparadoxum and Butyrospermum. Afzelia Africana, Tamanrindus indica, Pakia biglobosa, Balanite aegyptiaca, fabia, and albida.

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 km^2.

A main road connects Gombe town to Kumo-Billiri town, and there is a subsidiary road that connects Kumo to the Maiganga coal mine. The villages, settlements, and farmlands are connected by small roads and walkways. The drainage pattern surrounding the Coal mine is dendritic (Fig. 1).

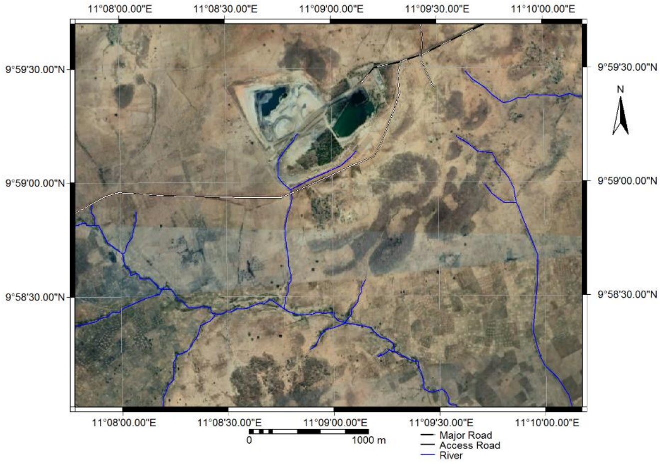

Figure 1. Satellite image of the study area showing excavated land ponds within the coal mine (Source: Google Earth 2023)

1.2. Geology

Figure 2 depicts the Upper Benue Trough's geologic sequence. The oldest layers are made up of continental deposits that rest unconformably on Precambrian Basement rocks from the Late Jurassic to the Albian Bima Formation. The uniformly-covered Cenomanian continental to marine Yolde Formation, with calcareous sandstones, shales, and sandstones at the base and sandstones at the top, covers the Bima Formation. In several places, the contemporaneous marine successions of the Pindiga and Gombe Formations unconformably cover the pre-mid-Santonian sequences (Fig. 3).

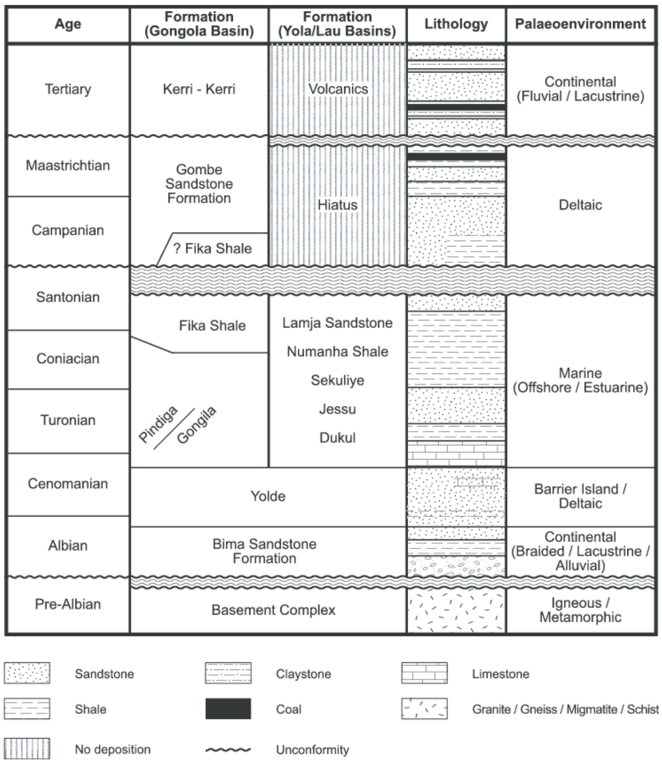

Figure 2. Stratigraphic succession in the Upper Benue Trough after [14]

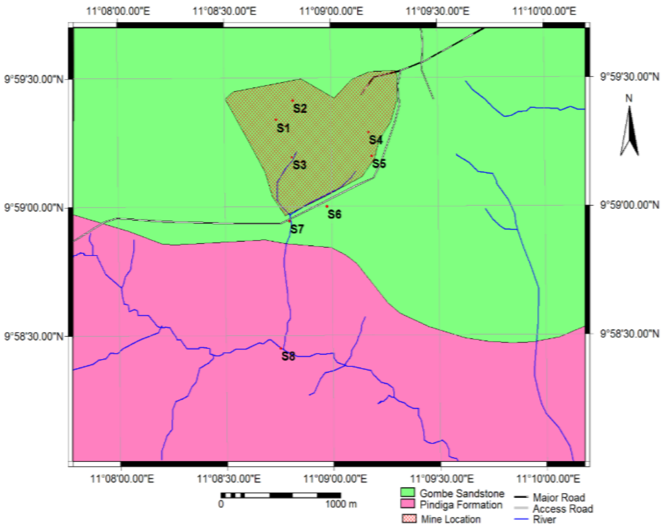

Figure 3. A geologic map illustrating the research area's sample collecting spots and the layout of the mine located within Gombe Sandstone (modified from [15])

The Paleogene Kerri – Kerri Formation's continental sandstones, siltstones, and shales mark the conclusion of the Upper Benue Trough's sedimentation [12]. Maiganga coal is hosted within the Maatrichtan Gombe formation of North-East Nigeria. It is a low-rank subbituminous coal [13].

2. Methods

2.1. Sample collection

Baseline data of the Maiganga coal mine was reviewed before carrying out a reconnaissance survey to collect reliable samples depending on availability within the coal mine and along the drainage/river channels using UNICEF standard procedure [15]. Plastic containers were used to collect water samples at each location; Mine Dam, Wetland, Drainage channel, hand-dug wells, sites and river channel. Samples bottles containers were rinsed thoroughly with the water from which samples were to be taken before being bottled. From every location, two samples were taken, and they were filtered to remove any suspended particles. Two drops of concentrated nitric acid were added to samples for cationic analysis to bring their pH down to less than 2, since this will help decrease or avoid the precipitation and adsorption of certain cations on the container walls and inhibit the growth of bacteria [4]. The samples were duplicated, labeled and corked tightly according to location and number.

2.2. Laboratory analysis

Samples were first homogenized into a representative sample form [16], and replicate samples were prepared to evaluate if evaluate whether the homogeneity assumption was accurate. It was vital to choose and perfect a digesting technique to break down organic materials and transform the analyte into a form appropriate for determination in order to get rid of matrix effects and other interference factors [17], digestion with acid aids in the elimination of organic components that could cause issues with the spectroscopic examination. Digestion can be carried out primarily through two methods: either through open or closed systems [18]. Open acid digestions were carried out on a lab hotplate in a beaker. The samples were placed in the fume hood for a few hours to allow for digestion. Strong oxidizing acids were also added to the sample and heated throughout the wet digestion process to allow the organic components to break down [19]. UV Spectrophotometer 752N with Atomic Absorption Spectrometer 210 VGP (AAS) To find out how much of each element was in the sample, spectrophotometers were utilized. Atoms and ions that absorb light at a certain wavelength improve the concept. This particular wavelength provides the energy (light) that the atom absorbs when it is created [20].

2.3. Statistical analysis

Principal component analysis (PCA), Pearson correlation analysis, contamination, and metal pollution indices were used in the data analysis process to evaluate the parameters under investigation. In specifically, the single-factor index analysis shown in Equation (1) was used to evaluate the Contamination Index (*Pi*) (Table 1 and Table 2) as:

$$P_i = \frac{C_n}{S_i}, \qquad (1)$$

where C_n represents the measured concentration of heavy metal, *n* in the sample while S_i indicates the relevant standard value for the metal [21].

Table 1. Standard of single factor pollution index [21]

Pi	Pollution levels
$\leq$ 0.4	Non-pollution
0.4-1.0	Slight polluted
1.0-2.0	Medium pollution
2.0-50	Heavy polluted
> 5.0	Serious polluted

Table 2. Grading standard for Single Factor Index

Sub index [22]	Quality status	Range [21]	Pollution level
$Pi < 1.0$	Clean	< 0.4	Non-polluted
$1.0 \leq Pi < 2$	Potential pollution	0.4-1.0	Slightly polluted
$2.0 \leq Pi < 3.0$	Slight pollution	1.0-2.0	Medium polluted
$3.0 \leq Pi$	Heavy pollution	> 2.0	Heavy/seriously polluted

The Pearson's correlation coefficient was calculated using the Statistical Package for Social Science (SPSS), version 23. The Pearson's coefficient was utilized in thi investigation to interpret the connections and exchanges between the various indicators [23] associated coefficients ranging from zero (0) to unity (1) as follows: a correlation with a negative number indicates emission from opposing processes, values approaching 0 suggest little or no linear relationship between the affected variables, and those at or near 1 suggest a very high correlation.

3. Results and discussion

In Table 3, the findings of the physico-chemical characteristics of the water samples that were gathered in the research region are summarized, and in Table 4, the terms Minimum, Maximum, Mean, Range, Standard Deviation, and Variance are found. As opposed to this, Figure 4 through Figure 6 show the data graphically.

3.1. Correlation analysis

The correlation matrix indicates a high positive correlation between Cadmium (Cd) and Copper (Cu) ($r = 0.954$) (Table 5). This suggests that the same processes in the aquifer are contributing to the enrichment of the water with both Cd^{2+} and Cu^{2+}. Because of this, the Cd^{2+} and Cu^{+} concentrations in the water were comparatively high due to the oxidative weathering of the ore minerals in the vicinity [24]. EC and Cl^- ($r = 0.852$), Mn^{2+} ($r = 0.995$), and Fe^{2+} ($r = 0.719$) have very strong correlations (Table 5), suggesting that the concentrations of these elements in the mine's surface water and groundwater system, as well as in Mn^{2+} and Fe^{2+}, are caused by similar geochemical processes, such as ion exchange reactions. In Table 3, TDS further confirms the source of these elements by showing a very good association with Cl^- ($r = 0.852$), Mn^{2+} ($r = 0.995$), and Fe^{2+} ($r = 0.720$). According to Table 5, there is a substantial positive connection between iron (Fe^{2+}) and Cl^- ($r = 0.914$) and Mn^{2+} ($r = 0.770$). This suggests that ion exchange reactions could be responsible for the mobilization of these ions in the mine pit water, surface water, and groundwater system.

Additionally, there is a high positive association ($r = 0.897$) between Chloride (Cl^-) and Manganese (Mn^{2+}), indicating that manganese loading in water may also come via the dissolution of chloride minerals [24]. Lead (Pb^{2+}) concurrently exhibits a substantial positive connection with both Cd^{2+} ($r = 0.728$) and Ca^{2+} ($r = 0.741$), which may be due to input from the local rock types.

Table 3. Physico-chemical parameters of collected water samples

S/No	Parameters, mg/l	S1	S2	S3	S4	S5	S6	S7	S8	NSDW	WHO
1	Cl^-	120	319	84	115	105	198	116	111	250	250
2	NO_3^{-2}	21.18	17.31	20.74	22.72	16.21	21.00	20.87	19.93	50	10
3	N	4.78	3.91	4.68	4.67	3.89	4.74	4.72	4.23	–	3
4	F^-	0.00	0.01	0.89	0.00	0.00	0.00	0.00	0.00	1.5	1.5
5	SO_4^{-2}	80	240	231	12	23	8	180	13	100	250
6	Ca^{+2}	0.0472	0.2941	0.6380	0.6778	0.6558	0.5511	1.1283	0.5788	–	–
7	Cu^{+2}	0.0000	0.1407	0.3890	0.4504	0.3504	0.5041	1.0152	0.4344	1.0000	0.3000
8	Mn^{+2}	0.2159	12.1080	0.2536	0.0363	0.1636	0.0257	0.2549	0.2003	0.2000	0.1000
9	Cr^{+2}	0.0000	0.0147	0.0190	0.0268	0.0165	0.0188	0.0176	0.0232	0.0500	0.1000
10	Mg^{+2}	27.551	30.066	27.804	15.309	20.313	11.862	27.533	19.229	20.000	–
11	Fe^{+2}	0.0809	0.1699	0.0417	0.0850	0.0850	0.1233	0.0748	0.1090	0.3000	2.0000
12	Cd^{+2}	0.1002	0.1056	0.1373	0.1171	0.1252	0.1195	0.1211	0.1232	0.003	0.0500
13	Pb^{+2}	0.02891	0.01564	0.05273	0.04379	0.03378	0.03228	0.05191	0.03821	0.01000	0.20000
14	Na^+	0.06	1.11	0.67	0.57	0.76	0.57	0.90	0.44	200.00	–
15	K^+	0.10	0.23	0.27	0.52	0.34	0.52	0.31	0.45	–	–
16	TDS	398	3491	458	300	454	85	514	389	500	300

NSDW – Nigerian Standard for Drinking Water; WHO – World Health Organization Standard

Table 4. Descriptive statistics for water in Maiganga Coal Mine and Environs

Descriptive Statistics					
	N	Min.	Max.	Mean	Std. Deviation
Chloride	8	84.0	319.00	146.00	77.39
Nitrate	8	16.2	22.72	20.00	2.16
Nitrogen	8	3.9	4.78	4.45	0.38
Fluoride	8	0.0	0.89	0.11	0.31
Sulphate	8	8.0	240.00	98.38	102.29
Calcium	8	0.0	1.13	0.57	0.313
Copper	8	0.0	1.02	0.41	0.30
Manganese	8	0.0	12.11	1.66	4.22
Chromium	8	0.0	0.03	0.02	0.01
Magnessium	8	11.9	30.07	22.46	6.72
Iron	8	0.0	0.17	0.10	0.04
Cadmium	8	0.1	0.14	0.12	0.01
Lead	8	0.0	0.05	0.04	0.01
Sodium	8	0.2	1.11	0.69	0.30
Potassium	8	0.1	0.66	0.43	0.19
TDS	8	85.0	3491.00	761.13	1110.96
Valid N (listwise)	8				

Furthermore, Table 5 shows a substantial positive connection (r = 0.913) between Nitrate (NO^{-3}) and Nitrogen N, indicating the influence of anthropogenic sources such as sewage leachate and the application of agrochemicals on farms. In addition, Potassium (K^+) displays a strong positive correlation with Ca^{2+} (r = 0.723) and Cd^{2+} (r = 0.728) (Table 5), indicating that these elements are derived from hydromorphic dispersion from the mine, Huang [25] reported similar finding.

The investigation area's heavy metal concentrations can be compared to certain regions of Nigeria to verify the effect of the Maiganga Coal mine on the region's water quality [26], where there are no mining activities. For instance, the Okaba, Onyeama and Ribadu Mining Sites [27], reported very low concentrations of heavy metals in groundwater than what is reported in the current study. Due in great part to the lack of mining activity in the area, groundwater concentrations of heavy metals are low. Due to the mining company's low influence on the environment, Adedeji et al [28] observed that the water from the various sources evaluated is generally within the WHO/NSDQW requirements for portable water. Backfilling the mined-out pits immediately after the removal of coal, aids considerably in eliminating the influx of pollutants.

Table 5. Pearson correlation matrices of physico-chemical parameters (numbers in bold indicate correlation coefficients ≥ 0.70) of the study area

	Cl	NO^{3-}	N	Fl^-	SO_4^{2-}	Ca	Cu	Mn	Cr	Mg	Fe	Cd	Pb	Na	K	TDS
Cl	1															
NO^{3-}	−0.378	1														
N	−0.413	**0.913****	1													
Fl^-	−0.314	0.134	0.235	1												
SO_4^{2-}	0.331	−0.173	−0.052	0.531	1											
Ca	−0.373	0.129	0.133	0.082	0.046	1										
Cu	−0.295	0.262	0.292	−0.033	0.03	**0.954****	1									
Mn	**0.897****	−0.506	−0.575	−0.123	0.572	−0.356	−0.364	1								
Cr	−0.119	0.15	−0.103	0.097	−0.214	0.636	0.523	−0.13	1							
Mg	0.157	−0.273	−0.143	0.327	0.856**	−0.159	−0.172	0.474	−0.535	1						
Fe	**0.914****	−0.41	−0.531	−0.568	0.001	−0.365	−0.279	**0.770***	−0.004	−0.079	1					
Cd	−0.535	0.004	0.037	0.65	0.042	0.644	0.494	−0.453	0.617	−0.198	−0.558	1				
Pb	−0.787*	0.526	0.549	0.502	0.046	**0.741***	0.69	−0.697	0.429	−0.068	−0.839**	**0.728***	1			
Na	0.061	−0.306	−0.306	0.565	0.661	0.549	0.373	0.313	0.475	0.375	−0.14	0.613	0.366	1		
K	−0.501	−0.218	−0.316	0.035	−0.289	**0.723***	0.576	−0.403	0.68	−0.308	−0.292	**0.728***	0.524	0.404	1	
TDS	**0.852****	−0.533	−0.597	−0.099	0.614	−0.324	−0.346	**0.995****	−0.143	0.542	**0.720***	−0.431	−0.657	0.359	−0.365	1

Hence, the possibility of water entering the mine pits to form dilute sulphuric acid leading to streams or river been acidic is a remote possibility. According to other researchers [29], there is a consistent drop in all metal concentration from November to March, which is consistent with a decrease in run-off. In general, coal samples have higher metal contents than silt samples do. The concentration trends of these metals suggest that they are subject to selective leaching. The sediments exhibit greater seasonal changes than the coal samples. All of the metals have positive correlations, according to correlation coefficients, which suggests that they come from the same place.

3.2. Total dissolved solids

The TDS readings for each water sample taken during the course of the sampling times shows which materials are present in the various water sources. It consists of dissolved and colloidal solids (Fig. 4). The primary dissolved solids in natural water are Na^+, K^+, Ca^{2+}, and Mg^{2+} [30].

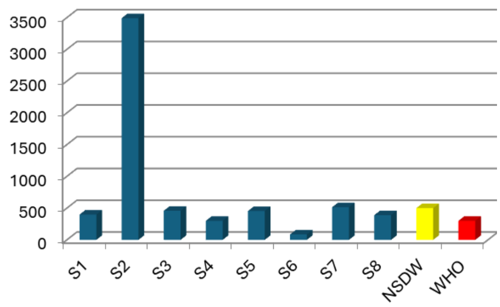

Figure 4. Graphical plot of TDS against some selected world standards (mg/l)

It is important to have moderate amounts of TDS in water since too little or too much of it might have an adverse effect on the water's quality. It is inappropriate to have a very low TDS concentration as this can result in a bland and tasteless flavor [31]. TDS levels for potable water met the 500 mg/l WHO standard as well as the 500 mg/l IFT and NSDW standards.

3.3. Anions and cations

All of the water sources under investigation – the well, the Earth Dam, the formation water, and the water holes along the stream channel – had usually high NO_3 concentrations. For instance, the NO_3 ranged from 16.2 to 22.72 mg/l (Table 3, Fig. 5c) which is above the WHO and IFT but for NSDW standard which pegs it peak on 50 can be considered acceptable in Nigeria [32] and not good for consumption but might effective for agricultural soil. There wasn't much farming going on in the region. The Formation water had 8.0 mg/l of SO_4 (Table 3 and 4, Fig. 5b), which increases gradually to 240 mg/l throughout the mine drainage channel. The mine drainage has the greatest concentration of 319 mg/l of Cl (Fig. 5a), which reduced to below detectable level at location S3 approaching the mine site's wetland. The formation water has a concentration of 84 mg/l of Cl. Location S1 along the mine drainage (Table 3) had the highest concentration of nitrogen, 4.78 mg/l (Fig. 5e).

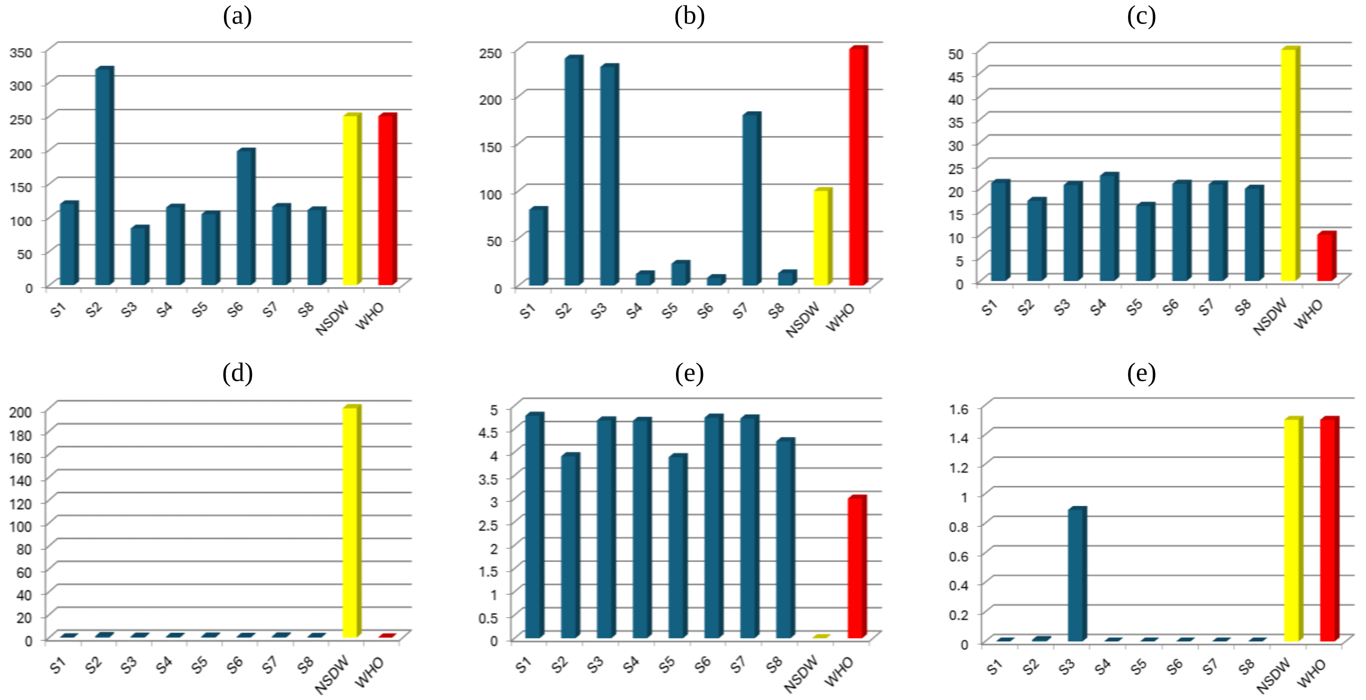

Figure 5. Anion and cations charts representation compares with some world standards (mg/l): (a) Cloride (Cl^-); (b) Sulphate (SO_4); (c) Nitrate (NO_3^{-2}); (d) Sodium (Na^+); (e) Nitrogen (N); (f) Fluoride (F^-)

The average concentration in water along the stream channel was found to be 4.74 mg/l, whereas the concentration in formation water is 3.9 mg/l. Along the community drainage channel, the concentration of Ca (Table 3) increased to 1.1283 mg/l at location S7 from a low of 0.0472 mg/l at S1. The concentration of well water was 0.5511 mg/l, and no NSDW, WHO, or IFT data were available for comparison. According to Table 3, potassium (K^+) concentrations vary from 6.75 mg/l in Formation water to 23.7 mg/l in the mine drainage channel. The concentration of magnesium in the water was 11.9 mg/l, reaching a maximum of 30.07 mg/l at the Mine's S2 location. Along the drainage channel into the main stream, the concentration of magnesium remained constant. Table 3 indicates that the concentration of Na in the Formation water ranges from 0.2 to 1.11 mg/l in the mine drainage at location S4, which is still along the mine drainage channel. The value of this concentration is 0.06 mg/l. While the content of Na in the water flowing downstream was somewhat constant at 0.90 mg/l, it was 0.57 mg/l in the well water at location S6.

3.4. Heavy metal concentration

High concentrations of metals, particularly copper (Cu), manganese (M)n, and cadmium (Cd), have been found in mine and well water. These findings have been linked to leachate water from coal mine waste effluents and overburden dump materials. The levels of Cd in our research location were higher than the WHO's recommended limits for drinking water [33] and IFT and NSDW [32] at some of the sampling locations. Nearly all of the sample locations had Cd concentrations over the WHO's recommended limits for drinking water (Fig. 6). The earth's crust and the region's geological formation can be blamed for the concentration of metals [34]. Heavy metal releases into the environment are known to be associated with coal mining [35]. The quantities of Cu and Mn were determined to be well within the desired limit, however they did not extend to all of the studied samples.

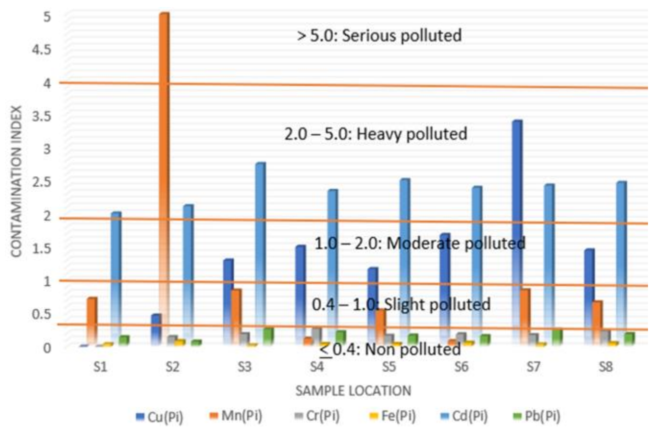

Figure 6. Metal pollution load index of heavy metals in water from the study area

Mn concentrations ranged from 0.0 to 12.11 mg/l on average, with a mean of 1.66 mg/l. However, at location S2 along the mine drainage, Mn concentrations were 12.11 mg/l ppb (Table 3). Although the Nigerian criterion for drinking water was met, the concentration of Cu at location S6 (well) was 1.02 mg/l, whereas other water sources in the region had concentrations ranging from 0.00 to 1.02 mg/l with a mean of 0.41 [32] makes it is within the allowable limit, the WHO and IFT standard is far above the limit (Table 3).

3.5. Pollution Index (*Pi*)

The results of the single-factor Pollution Index (*Pi*) analysis (Eq. (1)) were shown in Table 2, while Table 1 and Table 2 serve as guidelines for interpretation. Results (Table 6) show that in nearly all representative samples near the coal mine, where $Pi \geq 1.0$ was primarily observed, the *Pi* approached unity (i.e., $Pi \approx 1.0$) and even greater than the general standard. Typically, this trend of contamination index signified actual and potential water contamination with respect to heavy metals [6].

Table 6. Contamination Indices of heavy metals in the Surface and ground water of the study area

Sample location	Copper	*Pi*	Manganese	*Pi*	Chromium	*Pi*	Iron	*Pi*	Cadmium	*Pi*	Lead	*Pi*
S1	0.0000	0.0000	0.2159	0.7197	0.0000	0.0000	0.0809	0.0405	0.10022	2.0044	0.02891	0.1446
S2	0.14068	0.4689	12.1079	40.3597	0.01469	0.1469	0.1699	0.0850	0.10564	2.1128	0.01564	0.0782
S3	0.38901	1.2967	0.2536	0.8453	0.01899	0.1899	0.0417	0.0209	0.13734	2.7468	0.05273	0.2637
S4	0.45043	1.5014	0.0363	0.121	0.02683	0.2683	0.085	0.0425	0.11712	2.3424	0.04379	0.2190
S5	0.35043	1.1681	0.1636	0.5453	0.01653	0.1653	0.085	0.0425	0.1252	2.504	0.03378	0.1689
S6	0.50407	1.6802	0.0257	0.0857	0.01878	0.1878	0.1233	0.0617	0.11948	2.3896	0.03228	0.1614
S7	1.01523	3.3841	0.2549	0.8497	0.01756	0.1756	0.0748	0.0374	0.12108	2.4216	0.05191	0.2596
S8	0.43443	1.4481	0.2003	0.6677	0.02323	0.2323	0.109	0.0545	0.12321	2.4642	0.03821	0.1911

Subjecting Table 2 and Table 6 to an interpretative platform (Fig. 6) showed the actual polluted areas and locations at glance. The pollution sources are traced from the mine area as can be seen S2 from Figure 6. Thus, this kind of dataset determined the level of contamination [36], which can offer recommendations for the general management of the watershed. Therefore, as long as the mining activity is inevitable, a regulatory plan can be drawn up by Management to monitor wastewater discharge from the coal mine. Using this strategy can lessen the amount of illegal gangue that is disposed of and the amount of unpermitted excavation that creates paths for wastewater to enter the water table or flow into rivers or their tributaries. By this approach, metal pollution of the water supplies by mining activities across the region would vehemently be minimized. Consequently, it's critical to implement the use of water monitoring sensors that can identify and report any contamination in real-time in order to monitor the mine's discharge effluent and the degree of pollution in the surrounding area.

4. Conclusions

Coal mining which involves the extraction of coal deposits from the Earth's crust for various purposes, such as energy production, industrial processes, and more; has often leads to several environmental challenges, one of which is effluent discharge (release of liquid waste, often containing various pollutants and contaminants, into water bodies or the surrounding environment). From research of water samples collected from the drainage channel coming from Maiganga Coal Mine into the main stream shows that the effluent introduces some heavy metals, anions and cations which are harmful to both aquatic and animals when ingested.

The anions and cations; [Cl^- (84-319 mg/l), Fl^- (0-0.89 mg/l), SO_4^{2-} (8-240 mg/l) and Na^+ (0.06-1.11 mg/l)] fall within the WHO and Nigerian Standard for Drinking water quality (NSDWQ) except Nitrate and Nitrogen which is above the WHO (10), (3) permissible limit for drinking water but below the NSDWQ (50).

Heavy metals analyzed within the environment that Copper, Manganese and Cadmium are high in concentration and above both WHO and NSDWQ. However, Iron, Chromium and Lead with within the permissible limit. These elements probably will have resulted from the high acidity of the effluent.

These findings demonstrated that acid mine drainage, a consequence of coal mining operations, existed. There was no evidence that the effluents discharged from the coal mine had impacted the quality of the ground water when comparing the composition of the mine drainage channel with nearby well water sources. However, the surface water shows significant influence of mining activities on the water quality. If this is mitigated in real-time, it will go a long way in enhancing the Sustainable development goals (Goal No. 3; Good Health and Well-being, Goal No. 6; Clean water and sanitation, Goal No. 7; Affordable and Clean Energy and Goal No.14; Life on Land).

Author contributions

Conceptualization: KCA, MHMH, SI; Data curation: KCA, MHMH; Formal analysis: KCA; Funding acquisition: KCA; Investigation: KCA, MHMH, SAS; Methodology: KCA, MHMH; Project administration: MHMH, SI; Resources: KCA, MHMH; Software: KCA; Supervision: MHMH, SI, SAS; Validation: MHMH; Visualization: KCA, MHMH; Writing – original draft: KCA; Writing – review & editing: MHMH. All authors have read and agreed to the published version of the manuscript.

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Conflicts of interests

The authors declare no conflict of interest.

Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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Фізико-хімічна оцінка поверхневих вод у результаті гірничодобувної діяльності на вугільній шахті Майганга, штат Ґомбе, Нігерія

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Мета. Проведення комплексної фізико-хімічної оцінки стану поверхневих вод, що зазнали впливу гірничодобувних підприємств, з особливим акцентом на вміст важких металів.

Методика. Проби води було взято з різних місць на території вугільної шахти Майганга та навколо неї і проаналізовано їх із використанням стандартних лабораторних методів. Оцінка включала вимірювання фізико-хімічних параметрів, зокрема, температури, загального вмісту розчинених твердих речовин і концентрацій важких металів, таких як хром, свинець, марганець, кадмій і мідь. Крім того, були розглянуті катіони та аніони (кальцій, магній, натрій, калій, нітрат, сульфат хлориду та фторид), які можуть впливати на якість води. Ці параметри були обрані через їх значущість як показників якості води та потенційного забруднення.

Результати. Експериментально виявлено суттєві коливання вмісту хрому (0.00-0.03 мг/л), свинцю (0.00-0.05 мг/л), марганцю (0.00-12.11 мг/л), кадмію (0.01-0.14 мг/л) та міді (0.00-1.02 мг/л). Виявлено, що катіони та аніони, такі як кальцій (0.00-1.13 мг/л), магній (11.90-30.07 мг/л), натрій (0.20-1.11 мг/л), калій (0.10-0.66 мг/л), нітрат (3.90-4.78 мг/л), хлорид (84.0-319.0 мг/л), сульфат (8.0-240.0 мг/л) і фторид (0.00-0.89 мг/л) можуть впливати на рівень якості води у поверхневих водоймах, з яких були відібрані зразки.

Наукова новизна. Доведено наявність кислотного дренажу, спричиненого шахтними стоками, які обмежені поверхневими водами і не досягають ґрунтових вод та були знайдені шляхом аналізу даних з колодязів, ставків і струмків.

Практична значимість. Визначені зміни якості вод можна пояснити викидами кислотних чи лужних речовин, що виділяються внаслідок вугільнодобувної діяльності. Це є підґрунтям до вживання різних екологоорієнтованих заходів до покращення стану поверхневих вод.

Ключові слова: *поверхневі води, важкі метали, катіони та аніони, фізико-хімічний склад*

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