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Structural influence on the flow of solute contaminant in mine: Case study Maiganga Coal, Gombe State, Nigeria

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Abstract

Purpose. This research aims to better understand key components such as geology, lineament networks, and human-induced changes to improve methods for controlling contamination risks in mining environments. Specifically, the study examined how mining operations, structural alterations, and geological formations influence contaminant flow.

Methods. Autonomously generated lineaments from several data sets were analyzed to determine their lengths and orientations. Shuttle Radar Topography Mission-Digital Elevation Models (SRTM-DEM) and aeromagnetic data were explicitly used in this analysis. The research also uses PQWT and Abem SAS 1000 measurements to describe the sedimentary environment, particularly emphasizing the presence of thick, resistive sandstone layers at shallow to moderate depths. Additionally, the amounts of anions, cations, and metals in water samples were measured and compared to World Health Organization (WHO) and Nigerian Standard for Drinking Water Quality (NSDWQ) guidelines.

Findings. The results show that structural elements like thick, resistant sandstone layers affect solute movement in mining contexts. In high-energy settings, lineaments exhibit multi-directionality and substantial sedimentary strata. High quantities of metals such as copper, manganese, and cadmium are associated with leachate from mining waste, while water analysis showed excessive levels of nitrogen and nitrate.

Originality. This research uniquely integrates structural geology, solute transport, and contamination control, highlighting novel findings in lineament analysis and sedimentary environment characterization.

Practical implications. This research shows a pathway for industries to optimize resource extraction, improve waste management, and enhance water quality protection.

Keywords: *resistivity, lineament, mine environment, digitization, contaminant*

1. Introduction

Mining operations, especially those connected to industrial and artisanal operations, have long been known to be a significant source of environmental contamination. Introducing solute pollutants into subsurface habitats, which seriously harm soil and water quality, is one of the most urgent issues [1]. The structural features of the host rock and the surrounding environment significantly impact the migration and behavior of these solute pollutants within geologic formations [2]. Predicting contaminant paths, minimizing environmental harm, and directing sustainable mining methods depend on understanding these structural impacts [3].

Solute pollutants are frequently released during mining operations, and these releases can have detrimental effects on the environment and human health. The movement of these pollutants is significantly impacted by the structural features of the mine and is not only a product of hydrological processes [4]. Hydrogeological Influence refers to how an area's geological and hydrological characteristics interact to affect the quality of surface water bodies, such as rivers, lakes, and streams, due to mining activities [5]. Groundwater-surface water interactions, including flow patterns, recharge rates, and aquifer characteristics, play a significant role in determining the transport pathways of contaminants [6]. The direction of groundwater flow, the variation in pollutant concentrations, and the permeability of the aqueous medium all influence the migration law of contaminants. Pollutant migration direction is determined by groundwater flow direction; pollutant concentration difference dictates pollutant diffusion range, and pollutant migration speed is determined by aqueous media permeability [7].

Numerous geologic elements, such as lithological heterogeneity, porosity, permeability, and fracture networks, influence subsurface flow dynamics. Faults, joints, and bedding planes are structural characteristics that frequently act as preferential paths for fluid and solute migration, allowing pollutants to move far from their source [8]. In addition to aiding in the dispersion of pollutants, these structures also control flow rate, retention, and possible interactions with reactive minerals below the surface [9]. In mining contexts, where operations frequently cause changes in subsurface stress and hydrologic conditions, this complex interaction between structural characteristics and solute transport is especially pertinent [10].

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To recognize prevailing tendencies regarding water supply, quality, and trends that describe how the earth systems are changing [11]. First, a growing shortage of fresh water, which may impact human health, is expected because of rising demand and could be made worse by climate change. Second, because of soil erosion and fertilizer runoff, the amount of nutrients such as phosphorus and nitrogen that enter the ecosystem is anticipated to increase significantly [12]. This results in eutrophication in freshwater and algal blooms. As a result, the scientific community has significant problems identifying potential remedies to these trends [13].

The mine site's hydrogeological setting plays a crucial role in determining the fate and transport of contaminants in surface water [14]. Geology, hydrology, topography, and climate influence water movement and pollutants within the watershed [15]. Rivers get diffuse flows from the subsurface environment along their path, which modifies the physical conditions. As such, surface water and groundwater are highly dynamic, interdependent systems [16]. Mankind's influence is evident in the seasonal and temporal changes. According to model calibration and validation, over 90% of the models are correct with 95% confidence. The simulation of pollutant movement in a groundwater aquifer across a vast region (~300 km^2) was conducted with great precision (estimated standard error 0.049 m) [17]. Any pollution from the top surface migrates with groundwater velocity and the medium's dispersion characteristics, entering the groundwater regime. Pumping within the industrial area and pumping from nearby irrigation wells manage the hydraulic gradient in the watershed [18]. Several modules constructed under varied circumstances to replicate several processes indicated that surface water and groundwater in the leachate were contaminated. According to the simulation results, the low water level between the east and west sides caused the pollution plume to extend spatially and temporally [19].

Condon and Maxwell [20] examined the impact of topography on groundwater flows and water table depths throughout the contiguous United States (CONUS). They discovered that groundwater tables are frequently thought of as muted copies of topography. Kodešová et al. [21] found that different soil types have varied soil structures and that horizons significantly impact how contaminants move through soils and water flows through them.

The energy transition and international initiatives to slow climate change further highlight the necessity for vital mineral resources – many of which are obtained through mining operations. Global mining activity has increased because of this rising demand, raising the possibility of solute contaminant movement into the environment. Therefore, to create efficient remediation plans and guide sustainable mining operations, it is essential to research how structural geology affects the flow and transport of these contaminants and naturally occurring geological formations.

2. Materials and methods

2.1. Location

The research area is located in Gombe State's Akko Local Government Area (Fig. 1) and is within latitudes 11°08′47″ and 11°12′18″ and Longitudes 9°50′13″ and 10°00′00″ on a scale of 1:50000 Kaltungo NW, sheet 173. The study area covers an area of 10 km^2.

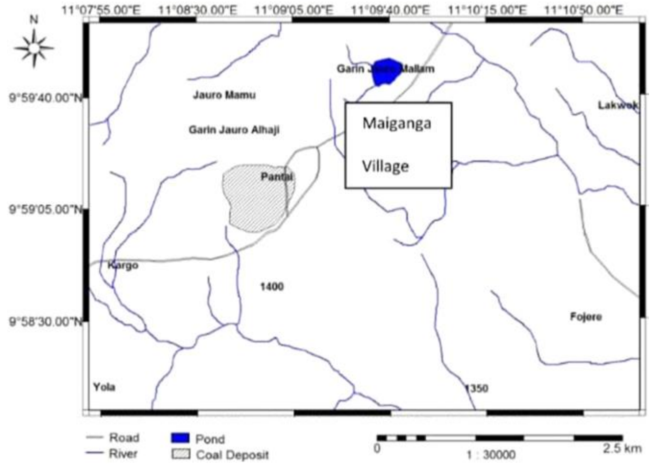


Figure 1. The study area's location, accessibility, and drainage map

A main road from Gombe to Kumo and a smaller one that connects Kumo to the Maiganga coal mine provide broad access to the area. Minor roads and walkways connect the numerous villages, communities, and farm areas.

A multidisciplinary methodology was used to examine how a mine's structure affects the flow of solute pollutants. This combines data analysis, Geophysical methods, field research, and laboratory tests. A successful study on solute contaminant flow depends on choosing a suitable mine site for structural analysis. Maiganga Coal Mine displays a range of structural features, including lineaments, fractures, and lithological units. The lithologic units that are all a part of the eastern, NE-SW trending Gongola arm of the Upper Benue valley were considered when digitizing the geologic map. Pindiga formations run from the study region's center to the map's southern portion.

In contrast, Gombe sandstones extend northward from the center (Fig. 2). Faults, fractures, and other structural features were extracted using high-resolution remote sensing and geophysical methods (using Abem SAS 1000 Lund and PQWT) to complement field mapping.

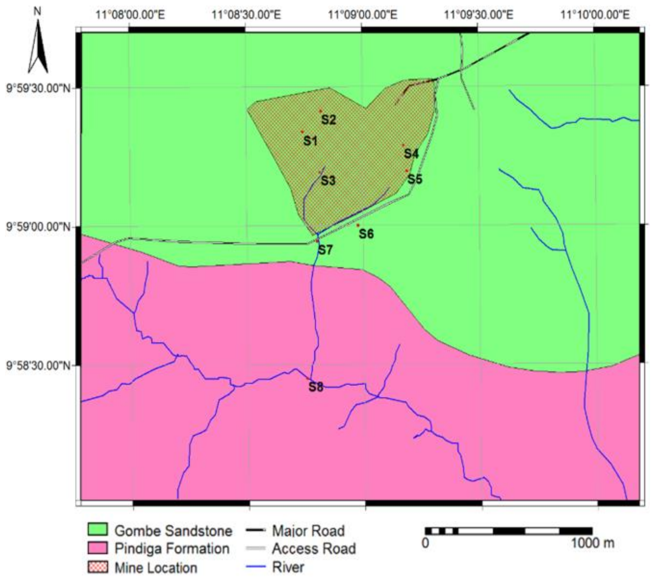


Figure 2. Geologic map of the study area showing the outline of the mine within Gombe Sandstone and sample collection points (modified from [22])

2.2. Digitization of structures from satellite images and aeromagnetic data

The process of digitizing geological structures from satellite images and magnetic data is intricate and utilizes remote sensing technologies to map and examine the features on Earth's surface. Urban planning, environmental monitoring, mineral extraction, and geological mapping all use this technology extensively [23].

Finding linear markings on the surface of the Earth is known as "lineament analysis". These features are frequently signs of underlying geological structures like faults, fractures, or the borders between different rock types. Lineament analysis is utilized for mineral discovery, structural mapping, and comprehending tectonic processes in aeromagnetic and satellite imaging [24]. Aeromagnetic surveys quantify Earth's magnetic field changes from the under-lying rock types. Aeromagnetic data lines frequently show variations in magnetic characteristics, which can be related to geological features [25].

2.3. Analyses in the laboratory

Before undertaking a reconnaissance assessment, baseline data for the Maiganga Coal Mine was examined, with sampling determined by site availability and UNICEF guidelines. To guarantee precision and dependability, water samples were gathered from multiple sites, filtered, acidified for cationic analysis, and carefully labeled samples [26]. To remove interference elements such as matrix effects [27], selecting and optimizing a digestion method to digest organic materials and convert the analyte into a suitable form for determination was necessary. Digestion with acid aids in the elimination of organic components that could cause issues with the spectroscopic examination. Digestion can be done through open or closed systems [28].

3. Results and discussion

3.1. Structural network of the area

Using satellite images, Landsat 8, aeromagnetic data, and Shuttle Radar Topography Mission (SRTM), a qualitative examination of the structures (lineaments) and interpretation of the lineaments of interest yields intriguing results. A look at how morphostructural features and the drainage system in the area show a great relationship. This includes abrupt channel morphological changes (Figs. 3-5), drainage patterns, fractures in the topography, highly linear behavior, and mountain range and peak alignments.

Analyzing the lineaments automatically generated from the multiple datasets, variations in orientation and length were observed. For instance, the multidirectional nature of the SRTM-DEM and aeromagnetic data was evident (Figs. 4 & 5). After the lineament orientation was determined, the lineaments of interest were used as inputs to define the main satellite lineaments in the study area (Fig. 3). According to Pour and Hasim [29], lineament offers significant insights into the degree of tectonic deformation, rock shearing and fracture, and rock permeability. Based on this, the lineament retrieved from Figure 4 coincided with the initial geological lineament created using the relevant satellite image as a guide [30].

Next, the qualitative analysis was added to the acquired satellite lineaments for examination in SRTM. After the lineaments of interest and the previously delineated aeromagnetic ones were observed, they were draped over one another to compare their relationships (Fig. 6).

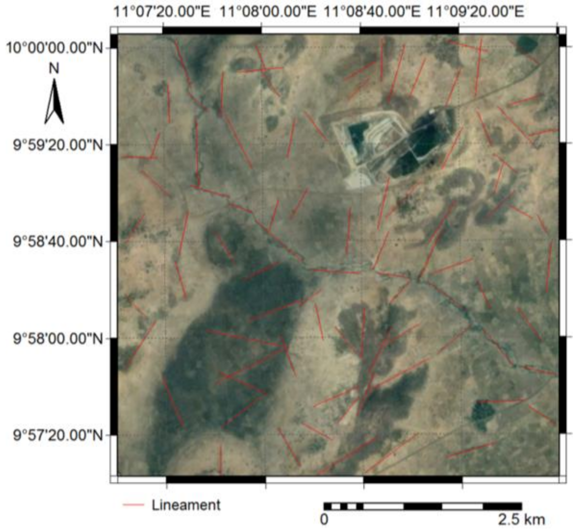


Figure 3. Lineament extracted from satellite image

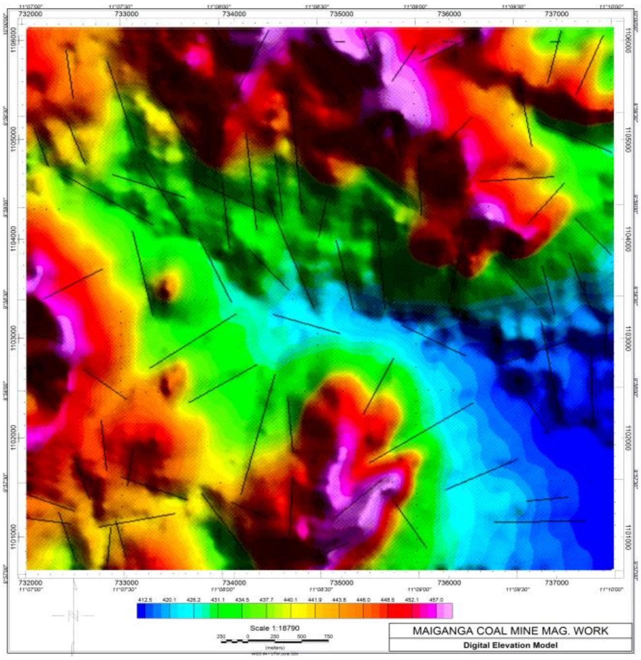


Figure 4. Lineament extracted from Shuttle Radar Topography Mission (SRTM)

The aeromagnetic results show that the azimuth affects the lineaments' orientation. In contrast, the SRTM-DEM and satellite image lineaments displayed a prevailing direction of NW-SE, and the detected lineaments for the aeromagnetic show a predominant orientation in the NE-SW direction. This indicates that the azimuthal angles affect the lineaments' prevailing orientation. For accurate and trustworthy results, at least four azimuth directions must be examined when combining data as the foundation for lineament detection [31].

Since this model homogenizes the territory and enhances the linear characteristics of the region, the lineaments show a greater adaptability to the surface characteristics based on the automatic extraction of lineaments. Biases in altitude, illumination, or linearities brought on by human activities have no bearing on this. However, based on this preliminary investigation using the SRTM data, the high-resolution magnetic data, and the Landsat image, areas of probable structural occurrence have been delineated and probed further using geophysical tools (Abem 100 series and PQWT) to verify the nature of the structure in the subsurface.

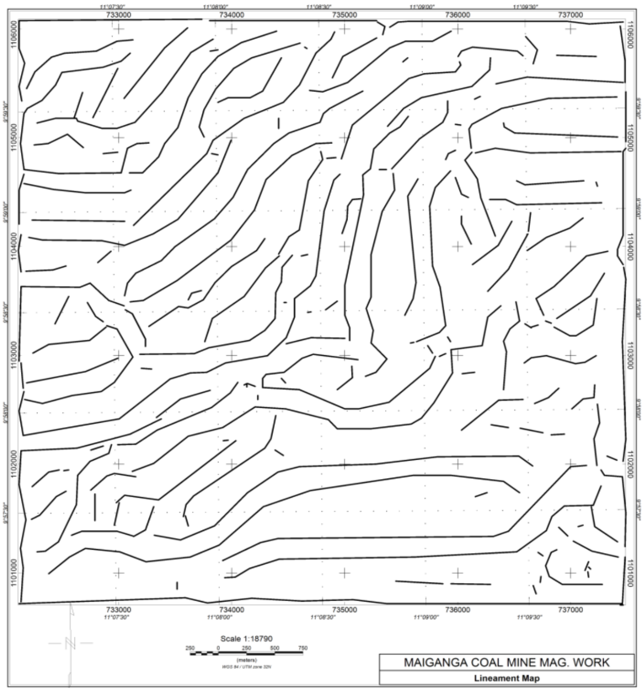


Figure 5. Lineament extracted from Aeromagnetic Data revealing their orientation in the NE-SW direction

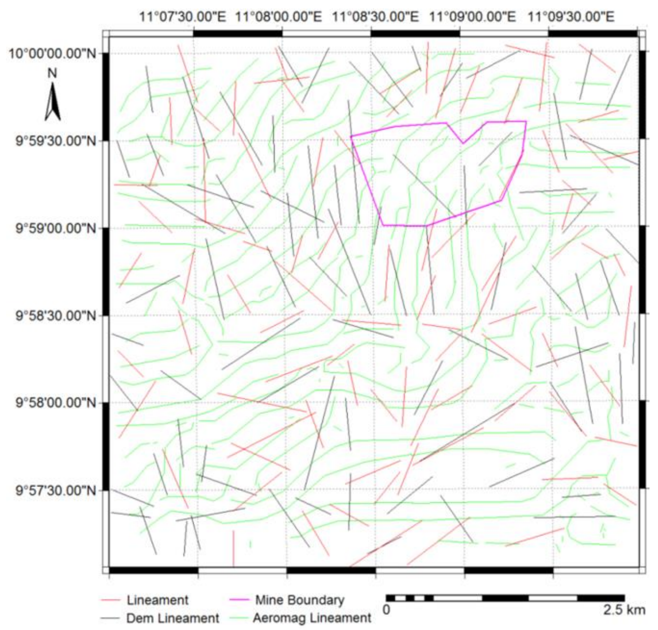


Figure 6. Combination of all Lineament extracted from Landsat, SRTM, and Aeromagnetic data

3.2. Profile analysis within the mine and around the mine

Profile lines drawn provide the findings of the profile line interpretation in the form of subsurface layer resistivity and depth-to-resistivity interfaces (Fig. 7); the satellite image below shows the whole position of all the profile lines taken [32].

3.3. Discussion of findings on the profile lines

The readings from the field and interpreted data are given in Figures 8-12, illustrating electrical resistivity curves and models. Interpretation of the obtained field data and assessment of the profile line curves using ABEM SAS 1000 and PQWT data were guided by knowledge of the area's geology.

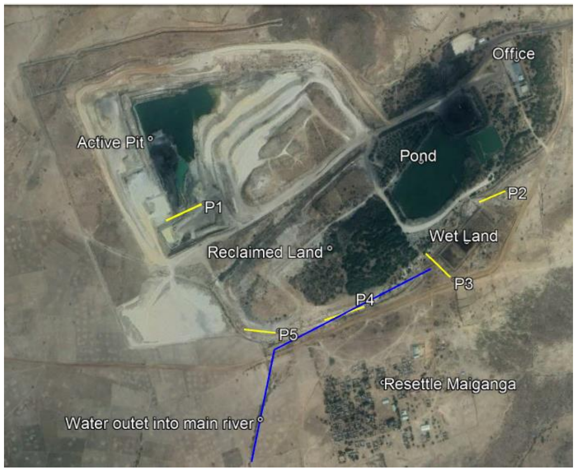
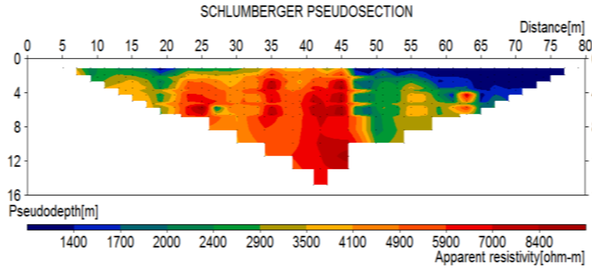


Figure 7. Satellite image showing the profile lines (P1-P5) taken during the geophysical mapping of structures

(a)



(b)

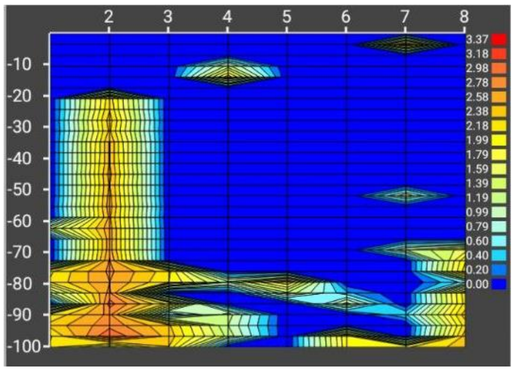


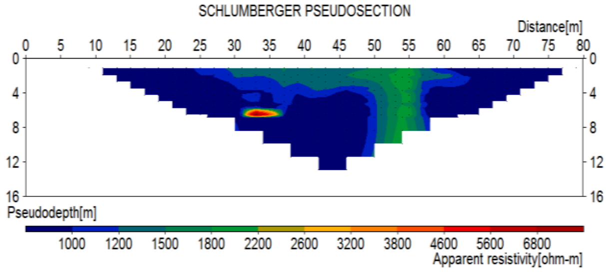
Figure 8. Structural analysis along the profile line P1: (a) Pseudo section showing apparent resistivity with some anomalous bodies 20-45 m horizontally running (Abem SAS 4000 series); (b) PQWT profile line confirming structures seen while running ABEM profile around point 42 to 50 m which could serve as a conduit for water seepage in a sandstone environment

Removing the vegetative cover from the earth's surface in the study area lays loamy soil, Ferrougenise Lateritic soil, and/or silty/lateritic topsoil. Between 0.5-3.0 m below the surface is a geologic layer characterized by shale to sandstone intrusion. However, from the mine pits, there are variations in the soil content; the one at the hilltop shows more small grain sandstone material mixed with shale (Profile Line 1), while the other at the lower end (Profile Line 5) shows more of silty to sandstone material but coursing northward [33].

The 2D Pseudo-section from SW-NE (Fig. 8a, b) shows the apparent resistivity with depth of some anomalous concentration of sandstone from 3-25 m depth, occurring at a depth of 2-15 m (Abem Lund). The resistivity values range from 4100-7000 ohm-m.

At the same time, the PQWT section shows resistivity of (1.19-3.39) with depth having some anomalous sandstone bodies at a distance of 3-4 m and a depth of 12-100 m and another at a distance of 1-2 m and a depth of 3-10 m depth.

(a)



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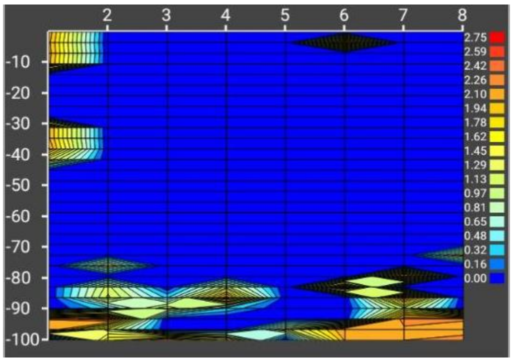
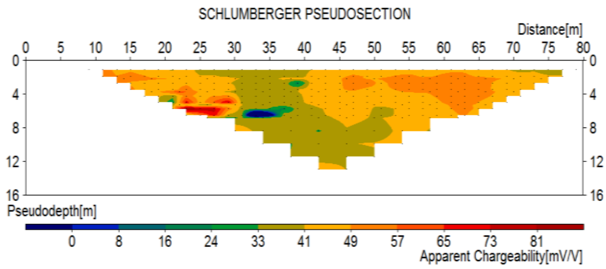


Figure 9. Structural analysis along the profile line P2: (a) Pseudosection showing apparent resistivity with anomaly picked at 50-55 m (Abem SAS 4000 series); (b) PQWT confirming the presence of structures seen in apparent resistivity from 50 to 58 m which is a possible conduit solute contaminant

(a)



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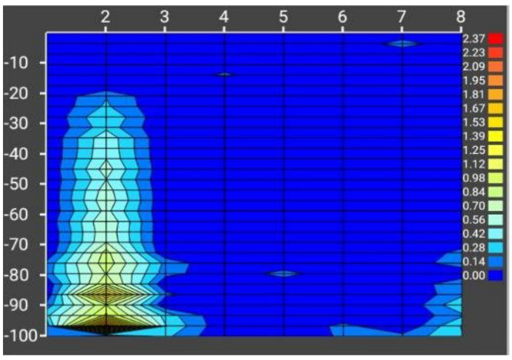
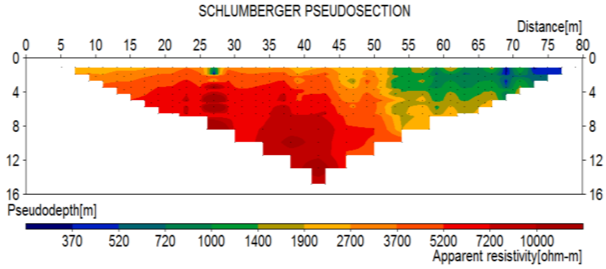


Figure 10. Structural analysis along the profile line P3: (a) Pseudosection showing apparent resistivity with some sparse anomalous bodies (Abem SAS 4000 series); (b) PQWT profile line showing the structure to be extensive vertically at point 25 to 33 m

(a)



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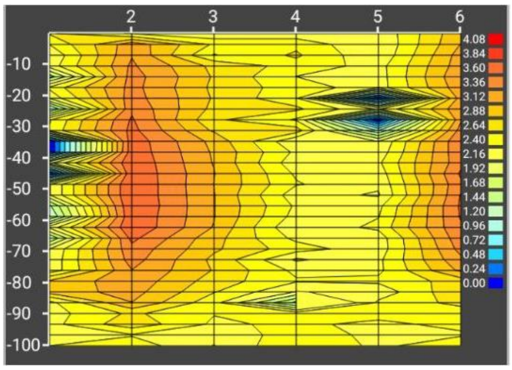
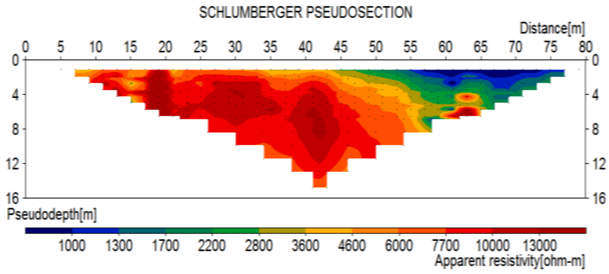


Figure 11. Structural analysis along the profile line P4: (a) Pseudosection showing apparent resistivity with high anomalous bodies (Abem SAS 4000 series); (b) PQWT profile line confirming the structures seen from ABEM profile line around point 35 to 42 m sandstone exposure to the near-surface to 100 m deeply seated

(a)



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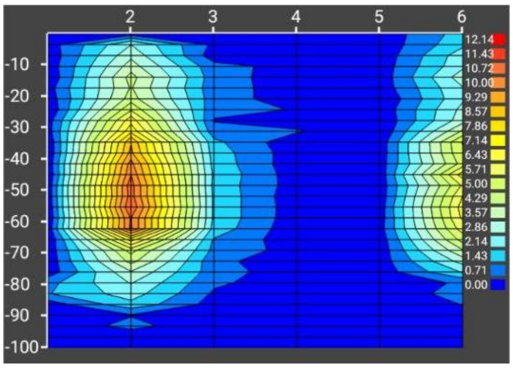

Figure 12. Structural analysis along the profile line P5: (a) Pseudosection showing apparent resistivity of anomalous bodies (Abem SAS 4000 series); (b) PQWT profile line confirming the structures seen from ABEM profile line around point 40 to 46 m, which could serve as a conduit for water seepage in a sandstone environment

The 2D Pseudosection from Southwest-Northeast (Fig. 9a, b) shows apparent resistivity with depth of some sandstone bodies at a distance ranging from 2 to 12, while the PQWT resistivity with depth shows some concentration of sandstone bodies at a distance of 2-3 m thick and a depth of 0-25 and 70-100 m. The 2D Pseudosection from Northwest-Southeast (Fig. 10a, b) shows apparent resistivity with a depth of some anomalous bodies at a distance ranging from 10 m thickness, occurring at a depth of 2-7 m and has a resistivity value of 1900-2400 ohm-m. At the same time, the PQWT resistivity of thickness 0.24-2.79 with depth showing some anomalous ore bodies at a distance of 10-100 m.

The 2D Pseudosection from East-West (Fig. 11a, b) shows the apparent resistivity with depth of some anomalous bodies a thickness of 45 m, occurring at a depth of 2-12 m and has a resistivity value of 3700-7200 ohm-m. The PQWT resistivity ranges from 0.48 to 4.08 millivolts, with depth showing some anomalous sandstone with a width of 25-30 m occurring at a depth range of 1-100 m. The 2D Pseudosection from East-West (Fig. 12a, b) shows apparent resistivity with depth of some anomalous bodies with thickness ranging from 10 to 55 m, occurring at a depth of 2-15 m and a resistivity values range of 6000-10000 ohm-m similar to Figure 8a. The PQWT has resistivity values of 0.71-12.14 millivolts range and depth, showing some anomalous sandstone bodies of thickness range 1-4 m and a depth from 1 to 80 m.

The thick resistive layers near the surface suggest a sedimentary environment dominated by coarse-grained deposits, such as sandstones. These layers are typical in fluvial, deltaic, or coastal environments where high-energy conditions allow for the deposition of coarser materials. The 2D pseudosection data and the PQWT measurements indicate a sedimentary environment characterized by thick, resistive sandstone bodies at shallow to moderate depths. These features suggest a high-energy depositional environment with significant geological processes contributing to forming well-consolidated sedimentary layers. Understanding these structural characteristics is crucial for further geological and hydrogeological assessments, particularly as it supports the transport of solute contaminants into the sub-surface.

3.4. Elements concentration in water

The cations and anions are Na^+ (0.06-1.11 mg/l), Fl^- (0.0-0.89 mg/l), SO_4^{2-} (8-240 mg/l), and Cl^- (84-319 mg/l). Nitrogen and nitrate are above the WHO-permitted limit for drinking water but below the Nigerian Standard for Drinking Water Quality (NSDWQ). Fall within both the WHO and NSDWQ standards. High concentrations of metals, particularly copper (Cu), manganese (M), and cadmium (Cd) have been found in the mine and well water. These discoveries have been linked to leachate water from overburden dump materials and coal mine waste effluents (Table 1). The WHO's recommended limits for drinking water concentrations of Cd were exceeded [34] and NSDW [35] at some of the sampling locations. Metals concentration can be attributed to the earth's crust and the geological formation of the study area [36]. It is well-recognized that coal extraction contributes to the environmental release of heavy metals [37]. Except for the Cu and Mn concentrations, which did not vary throughout the analysis of all samples, the other metals were all determined to be well within the desired limit.

The concentration of Cu in the collected water sources varied from 0.0 to 1.02 mg/l with a mean of 0.41; the concentration of Cu at location S6 (well) was 1.02 mg/l. The WHO and NSDQW standard is well above the limit, even if the Nigerian drinking water standard [35] states that it is below the permitted range (Table 1). Except for position S2 along the mine drainage, where Mn concentration was 12.11 mg/l ppb, the concentration of Mn was primarily within the range of 0.0-12.11 mg/l, with a mean of 1.66 mg/l (Table 2).

Table 1. Physico-chemical parameters of collected water samples during the dry season (February)

S/No	Parameters (mg/l)	S1	S2	S3	S4	S5	S6	S7	S8	NSDW*	WHO*
1	Chloride	120	319	84	115	105	198	116	111	250	250
2	Nitrate	21.18	17.31	20.74	22.72	16.21	21.00	20.87	19.93	50	10
3	Nitrogen	4.78	3.91	4.68	4.67	3.89	4.74	4.72	4.23	–	3
4	Flouride	0.00	0.01	0.89	0.00	0.00	0.00	0.00	0.00	1.5	1.5
5	Sulphate	80	240	231	12	23	8	180	13	100	250
6	Calcium	0.0472	0.2941	0.638	0.6778	0.6558	0.5511	1.1283	0.5788	–	–
7	Copper	0.0000	0.1407	0.3890	0.4504	0.3504	0.5041	1.0152	0.4344	1.0	0.3
8	Manganese	0.2159	12.108	0.2536	0.0363	0.1636	0.0257	0.2549	0.2003	0.2	0.1
9	Chromium	0.0000	0.0147	0.0190	0.0268	0.0165	0.0188	0.0176	0.0232	0.05	0.1
10	Magnesium	27.551	30.066	27.804	15.309	20.313	11.862	27.533	19.229	20	–
11	Iron	0.0809	0.1699	0.0417	0.085	0.085	0.1233	0.0748	0.109	0.3	2.0
12	Cadmium	0.1002	0.1056	0.1373	0.1171	0.1252	0.1195	0.1211	0.1232	0.003	0.05
13	Lead	0.02891	0.01564	0.05273	0.04379	0.03378	0.03228	0.05191	0.03821	0.01	0.2
14	Sodium	0.06	1.11	0.67	0.57	0.76	0.57	0.90	0.44	200	–
15	Potassium	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

*World Health Organization (WHO) Standard and the Nigerian Standard for Drinking Water (NSDW) [38]

The investigation area's heavy metal concentrations can be compared to specific regions of Nigeria to verify the effect of the Maiganga Coal mine on the region's water quality [38], where mining activity is nonexistent. In contrast to the findings of the current investigation, the Okaba, Onyeama, and Ribadu Mining Sites [39] found extremely low quantities of heavy metals in groundwater.

This work presents a critical and comprehensive investigation into the structural geology and its influence on solute contaminant flow within the Maiganga Coal Mine, Gombe State, Nigeria. The methodology integrated geophysical data (including ABEM SAS and PQWT profiles), remote sensing, and aeromagnetic analyses alongside laboratory water quality assessments.

Table 2. Water-related descriptive statistics for Maiganga Coal Mine and Environs during the dry season

Descriptive Statistics					
Parameters	N	Minimum	Maximum	Mean	Std. Deviation
Cl^-	8	84.0	319.00	146	77.39
NO_3^{2-}	8	16.2	22.72	20.00	2.16
N	8	3.9	4.78	4.45	0.38
F^-	8	0.0	0.89	0.11	0.31
SO_4^{2-}	8	8.0	240.00	98.38	102.29
Ca^{2+}	8	0.0	1.13	0.57	0.313
Cu^{2+}	8	0.0	1.02	0.41	0.30
Mn^{2+}	8	0.0	12.11	1.66	4.22
Cr^{2+}	8	0.0	0.03	0.02	0.01
Mg^{2+}	8	11.9	30.07	22.46	6.72
Fe^{2+}	8	0.0	0.17	0.10	0.04
Cd^{2+}	8	0.1	0.14	0.12	0.01
Pb^{2+}	8	0.0	0.05	0.04	0.01
Na^+	8	0.2	1.11	0.69	0.30
K^+	8	0.1	0.66	0.43	0.19
TDS	8	85.0	3491.00	761.13	1110.96

The study highlights the interplay between structural features and their environmental impact by correlating geological formations, such as thick resistive sandstone layers, with contamination pathways. This interdisciplinary approach underscores the significance of geological factors in pollutant migration and provides practical implications for enhancing water quality, optimizing resource management, and guiding sustainable mining practices.

4. Conclusions

The automatic extraction of lineaments demonstrates high adaptability to surface characteristics by homogenizing the territory and enhancing the linear features of the region. This method effectively mitigates biases related to altitude, illumination, or human-induced linearities, ensuring a more accurate representation of the geological features. The magnetic lineaments identified from this analysis likely result from various geological phenomena, including contacts between rocks of differing magnetic susceptibilities, edges of structural features such as faults or intrusives, and minera-lized zones within faults.

All of the analyzed anions and cations are within the limits of the NSDWQ and the WHO, except for nitrogen and nitrate, which are both above the WHO-permitted limit for drinking water but below the NSDWQ. There is a significant percentage of copper, manganese, and cadmium above both WHO and NSDWQ. Iron, chromium, and lead are all within acceptable bounds. The high acidity of the effluent is most likely what led to these components. These findings demonstrated the existence of acid mine drainage, a consequence of coal mining operations.

The originality of this work is evident in its multidisciplinary methodology, combining field measurements, laboratory analyses, and advanced data digitization techniques to assess contaminant pathways comprehensively. By correlating structural geology with water quality parameters, the research highlights critical interactions between mining activities and environmental impacts, particularly regarding the elevated concentrations of metals like copper, manganese, and cadmium in water sources. This approach provides a robust framework for sustainable resource management, offering practical insights for mitigating contamination risks and protecting water quality in mining.

Author contributions

Conceptualization: KCA, MHMH; Data curation: KCA; Formal analysis: KCA, SI; Funding acquisition: KCA; Investigation: KCA; Methodology: KCA, MHMH; Project administration: MHMH; Resources: KCA; Software: KCA; Supervision: MHMH, SI; Validation: MHMH; Visualization: SI; Writing – original draft: KCA; Writing – review & editing: KCA, 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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Структурний вплив на потік розчинених забруднювачів у шахті: на прикладі родовища Маїганга, штат Гомбе, Нігерія

К.К. Алувонг, М.Х. Хашим, С. Ісмаіл

Мета. Визначення ключових чинників, таких як геологія, лінеаментні мережі та антропогенні зміни, для вдосконалення методів контролю ризиків забруднення у гірничодобувних середовищах. Дослідження сфокусовано безпосередньо на впливі гірничих робіт, структурних змін та геологічних формацій на рух забруднювачів.

Методика. Автономно згенеровані лінеаменти з кількох наборів даних були проаналізовані для визначення їх довжини та орієнтації. У цьому аналізі використовувалися дані SRTM-DEM та аеромагнітні дані. Крім того, вимірювання PQWT і Abem SAS 1000 дозволили охарактеризувати осадове середовище, з особливим акцентом на наявності товстих, стійких піскових шарів на невеликих і середніх глибинах. Проведено аналіз концентрацій аніонів, катіонів та металів у пробах води з порівнянням їх із рекомендаціями Всесвітньої організації охорони здоров'я та Нігерійського стандарту якості питної води.

Результати. Виявлено, що у гірничодобувних контекстах структурні елементи, такі як товсті стійкі піскові шари, впливають на рух розчинених речовин. Визначено, що у висординамічних умовах лінеаменти демонструють багатонаправленість і значні осадові шари. Визначено, що високі концентрації металів, зокрема міді, марганцю та кадмію, пов'язані з вилуговуванням із шахтних відходів, тоді як аналіз води виявив перевищення рівнів азоту та нітратів. Встановлено, що підвищена кислотність стічних вод сприяє мобілізації металів, що загрожує якості водних ресурсів.

Наукова новизна. Дослідження унікально інтегрує структурну геологію, транспорт розчинених речовин та контроль забруднень, підкреслюючи нові результати аналізу лінеаментів і характеристик осадового середовища.

Практична значимість. Дослідження демонструє шляхи для оптимізації видобування ресурсів, покращення управління відходами та підвищення захисту якості води.

Ключові слова: *електроопір, лінеаменти, гірниче середовище, оцифрування, забруднювач*

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