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THE KORBA COAL MINING ZONE IN INDIA ASSESSMENT OF RISK HEALTH AND POLLUTANT SOURCES

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ABSTRACT

Water pollution presents a considerable ecological hazard, especially in rapidly industrializing areas like Korba. This study examines deficiencies in health risk assessment and pollutant source identification in the region. The study indicated that the amounts of Na^+, Ca^{2+}, F^-, Mn, As, Mo, Sr, and Ni were beyond the allowable thresholds for potable water. The Heavy Metal Pollution Index (HMPI), and the Heavy Metal Evaluation Index (HMEI), all showed that the main heavy metals found in surface and sub-surface water sources from the Korba coal mines were manganese (Mn), cadmium (Cd), molybdenum (Mo), cobalt (Co), and nickel (Ni). Fluoride (F^-) was recognized as a significant pollutant.

The findings highlight an urgent necessity for pollution control, namely addressing As, F^-, and Mn, to safeguard public health. Regular monitoring, filtration, and purification are crucial for guaranteeing safe drinking water in the region.

Keywords: Surface and sub-surface water source; Heavy metal mining waste; Hazardous elements

Abbreviation

HMPI	Heavy Metal Pollution Index
HMEI	Heavy Metal Evaluation Index
ERA	Environmental Risk Assessment
T	Turbidity
TH	Total hardness
TDS	Total dissolved solids
A	Alkalinity
Pb)	Lead
Cd	Cadmium
As	Arsenic
Hg	Mercury
F	Fluoride
EC	Electrical conductivity
SECL	South Eastern Coalfields Limited
HDPE	High-density polyethylene
WHO	World Health Organization
BIS	Bureau of Indian Standard
USEPA	United States Environmental Protection Agency
APHA	American Public Health Association

INTRODUCTION

Surface and sub-surface water sources have become a major environmental concern globally (Nichan and Khelil, 2015; Boubou-Bouziani, 2015; Bahir et al., 2015; Peng et al., 2022; SDGs, 2015; Aroua, 2022; Aroua, 2023), particularly in regions impacted by heavy metal mining activities (Kambiré et al., 2014; Benhamza et al., 2015, Tanouayi et al., 2015). Mining operations commonly discharge significant amounts of hazardous substances, including various heavy metals, into the surrounding ecosystems (Ahoudi et al., 2015; Coyte et al., 2019; Dhakate et al., 2023; Ukah et al., 2018), which can greatly affect both soil and water resources. Metals like arsenic, lead, cadmium, and mercury are especially problematic due to their long-lasting presence in the environment (Tohouri et al., 2017; Mohammadpour et al., 2023; Ozoko et al., 2022), their tendency to accumulate within living organisms, and the substantial health risks they pose to both ecosystems and human populations. Therefore, evaluating the mining-affected areas is crucial for determining contamination levels, understanding public health risks, and assessing the broader environmental consequences (Baba-Hamed, 2021; Jiang et al., 2021; Ukah et al., 2020; Chadee et al., 2024b).

The extraction, processing, and refining stages of ore production produce heavy metal mining waste. These procedures frequently use chemical agents and large quantities of water, and if discharged without proper treatment, this waste can contaminate nearby water sources. Mining pollutants can infiltrate sub-surface, rivers, lakes, and other bodies of water, often resulting in high metal concentrations that surpass the safety limits set by environmental authorities. Once in the water, these pollutants can travel significant distances, spreading the contamination over wide areas (Adjagodo et al., 2016; Waikhom et al., 2023; Chabokpour et al., 2024). This spread of pollution compromises drinking water sources and impacts agriculture, aquaculture, and local biodiversity, as metals make their way into the food chain through plants, fish, and other organisms (Lin et al., 2022). Consequently, comprehensive monitoring and management near mining areas are essential to reduce these harmful effects.

Assessing surface and sub-surface water sources impacted by heavy metal mining waste is essential for reservoir optimization (Mezenner al., 2022; Verma et al., 2023; Mehta et al., 2024; Mehta et al., 2023; Verma et al., 2024b; Verma et al., 2024c; Verma et al., 2021; Verma et al., 2024a), particularly in a fluctuating environment. Mining runoff containing heavy metals can contaminate reservoirs, endangering drinking water supplies, ecosystems, and agricultural applications (Azharuddin et al., 2022; Sahu et al., 2022; Sahu et al., 2023). EPANET modeling facilitates the monitoring of pollution dispersion, evaluation of concentration patterns, enhancement of treatment strategies inside water networks for improved distribution safety, and design and management of water distribution networks (Hountondji and Codo, 2019; Berrezel et al., 2023; Tandel et al., 2023; Kouloughli and Telli, 2023; Verma et al., 2022c; Dhiwar et al., 2021). The Surface and sub-surface water source quantifies contamination levels and identifies important regions requiring remediation (Patel et al., 2023b; Patel et al., 2023d). Moreover, it is essential to sustain environmental flows to protect aquatic ecosystems, ensuring a balance between water extraction and ecological integrity, especially during pollution (Hounkpe et al., 2017). The quality of surface and sub-surface water is affected by seepage from mining waste, requiring evaluations of both surface and sub-surface to assess the overall health of the system (Patel et al., 2023c; Surati et al., 2022). Comprehending these tendencies facilitates enhanced management and treatment, aiding in the mitigation of climate-induced alterations in water supply and flow dynamics.

In India, significant contributors to water pollution comprise inadequate industrial waste management, noncompliance with Central Pollution Control Board regulations, and insufficient public knowledge regarding safe water usage (Nivetha & Sangeetha, 2020). Numerous Indian states, such as Tamil Nadu, Singrauli, Odisha, Jharkhand, Madhya Pradesh, Assam, Meghalaya, and West Bengal, have documented the detrimental impacts of anthropogenic water pollution

Mining activities, particularly coal extraction, are essential for facilitating economic growth by satisfying the need for energy and raw materials. Nonetheless, these activities also raise significant environmental issues, especially due to the accumulation of trash containing dangerous heavy metals. The Korba coal mining region in Chhattisgarh, India, is essential for coal production and electricity generation, although it has concurrently emerged as a focal point for environmental deterioration. The inadequate management and disposal of mining waste have resulted in heavy metal contamination of soil, water, and air, posing significant threats to local ecosystems and human populations (Mohanty et al., 2001; Singh et al., 2010). As the environmental repercussions of such activities escalate, the imperative for effective and ongoing monitoring of toxins becomes crucial to avert long-term harm.

Environmental Risk Assessment (ERA) frameworks aim to pinpoint and measure risks associated with hazardous compounds, like heavy metals, providing crucial data for risk management to decision-makers. Historically, environmental monitoring has depended on laboratory-based methods necessitating manual sampling, which can be laborious, costly, and susceptible to delays (Chadee et al., 2024a). Conversely, new advancements in sensor-based technology provide real-time environmental monitoring, resulting in expedited and more precise evaluations. Environmental monitoring systems can incorporate sensors designed to detect heavy metal contaminants, such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg), for ongoing data acquisition.

This study examines the Korba coal mining zone, where significant mining activities and coal-fired thermal power plants have led to the emission of detrimental pollutants into the environment. The main aim of this project is to employ sensor-based environmental monitoring methods to evaluate the degree of heavy metal pollution resulting from mining waste. This study's findings will offer practical insights into the environmental hazards presented by these contaminants and suggest sustainable approaches for pollution reduction and waste management.

Furthermore, the existence of coal-fired thermal power plants in the Korba region intensifies pollution levels through the emission of pollutants including sulphur dioxide, nitrogen oxides, and particulate matter. These pollutants, along with heavy metals from mining waste, contribute to the contamination of air, soil, and water. A recent report by Kumar et al. (2019) indicates that the amalgamation of mining waste and emissions from power plants in Korba has resulted in significant ecological disturbances, including diminished agricultural output and sub-surface water contamination. Therefore, we urgently need an efficient monitoring and mitigation approach to address these environmental concerns.

This study seeks to determine the Heavy Metal Pollution Index (HMPI), and the Heavy Metal Evaluation Index (HMEI) of the surface and sub-surface water source. The research also examines the concept that harmful substances in water, especially in sub-surface water, may derive from several sources. The findings will contribute to a valuable scientific archive, aiding future research, development, and sustainable use of water resources. Furthermore, this study will serve as a reference point for regulatory authorities to monitor sub-surface water and track contaminant levels effectively.

RELATED WORKS

The study of surface and sub-surface water sources in mining regions is essential due to the considerable environmental repercussions linked to mining operations. Water resources in these locations frequently experience contamination from pollutants like heavy metals, acid mine drainage, and sedimentation. A multitude of studies have concentrated on elucidating the impacts of mining on quality, quantity, and ecosystem health, alongside the management of water resources within mining environments.

Numerous studies have examined how mining affects surface and sub-surface water supplies. Sughapriya et al., (2018) examined the impact of mining operations on river systems in India, observing that the release of untreated mine effluent results in elevated concentrations of heavy metals. They emphasized the importance of monitoring and mitigating contamination to protect aquatic ecosystems and the surrounding communities. Menon et al., (2012) evaluated the influence of gold mining on surface water sources in the Amazon, emphasizing the ramifications of mercury pollution and its lasting effects on local ecosystems and human health.

In mining regions, surface water bodies, including rivers, lakes, and streams, frequently receive substantial runoff laden with suspended particles, chemicals, and metals from tailings and waste rock. Prasad et al., (2015) investigated the function of hydrological models in forecasting pollutant dispersion in mining areas. Their research emphasized the necessity for efficient water treatment facilities to alleviate the effects of surface water contamination and avert the dissemination of contaminants downstream.

Sub-surface water supplies in mining regions are susceptible to contamination by the intrusion of chemicals and waste generated by mining activities. Geetha and Gouthami (2016) examined the effects of mining on sub-surface water sources in Poland, which revealed that mining operations can alter the chemistry of sub-surface water, leading to elevated salinity and the introduction of hazardous chemicals such as arsenic, as reported by Kumar and Samalla (2019). This study highlighted the difficulties in monitoring and managing sub-surface water resources in mining regions, where contamination is often more challenging to identify and remediate than in surface water.

The excessive withdrawal of sub-surface water for mining activities, especially in open-pit and underground operations, can result in a substantial decline in local water tables, impacting both human and biological water requirements. Sengupta et al., (2019) conducted a study on the groundwater depletion associated with coal mining in Australia, highlighting the potential long-term ecological damage and reduced water availability for nearby communities.

Recent literature has increasingly emphasized integrated water resource management (IWRM) in mining regions to tackle surface and sub-surface water issues. Demetillo et al., (2019) offer a comprehensive approach to water management that integrates hydrological modeling, pollution mitigation, and sustainable water utilization strategies. This methodology is crucial in mining areas, where water resources are frequently scarce and significantly affected by mining activities. Liu et al. (2020) underscored the necessity for monitoring and adaptive management systems that account for both surface and groundwater sources in areas affected by mining (Hamid et al., 2020; Anuradha et al., 2018).

DESCRIPTION OF CASE STUDY

The Korba coal mining region in northern Chhattisgarh is an essential part of India's coal belt. It is situated at 22°21′N latitude and 82°42′E longitude (Figure 1), accompanied by the Hasdeo River and its tributaries. The area comprises a combination of plains, forested regions, and open-pit mining locations, with adjacent districts like Raigarh and Bilaspur also engaged in mining operations. The topography of Korba renders it a significant industrial zone while exposing it to environmental degradation due to mining and coal-based activities.

Three distinct seasons characterize Korba's tropical climate. Summers (April to June) are exceedingly hot, with temperatures reaching 45°C, resulting in arid conditions and a heightened risk of airborne pollution. In the monsoon season (July to September), substantial precipitation causes surface runoff, disseminating mining waste into adjacent water bodies and agricultural lands. Winters (November to February) are comparatively chilly, with pollutants accumulating in the air and soil, raising contamination hazards.

The region contains some of the largest coal mines in India, predominantly managed by South Eastern Coalfields Limited (SECL). We recognize prominent mines, such as Bagdeva, Dhewadih, Singhali, Pavan, Rajgamar, Surakachhar, Banki, Bagli, Manikpur, Kusmunda, and Gevra & Dipka for their substantial output of bituminous coal, which is essential for electricity generation. Nonetheless, these mining operations produce considerable waste, comprising heavy metals such as lead, mercury, and cadmium.

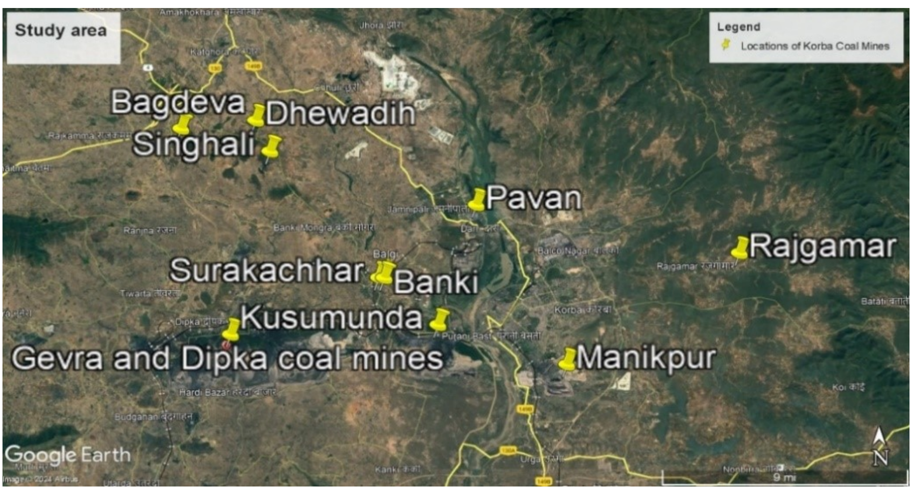

Figure 1: Study area map

MATERIAL AND METHODS

Sample Collection

We obtained 30 water samples from the Korba region during November and December to assess and ascertain the primary hydrogeochemical processes. We obtained samples from surface sources, including check dams, flowing water, and industrial/mine effluents, as well as from various aquifer levels, encompassing shallow and deeper sources such as dug wells, tube wells, and bore wells. We randomly selected sample sites and methodically allocated them in urban and industrial/mining areas to perform a thorough evaluation.

Among the 30 samples, 6 originated from industrial or mining effluents (mine outputs, ash pond slurry, decanted water), 10 from surface sources (streams and check dams), 7 from shallow aquifers, and 7 from deeper aquifers. We collected samples for ion analysis in 1-L high-density polyethylene (HDPE) bottles. We utilized an additional 250 ml polypropylene bottles to analyze for metals. The samples were filtered using 0.45 µm Whatman filter paper and acidified with HNO_3 (Loring and Rantala, 1992) according to the guidelines established by the American Public Health Association (APHA, 2017).

Analysis of Surface and sub-surface water sources

Table 1 summarizes and compares details of various physicochemical parameters with guidelines from BIS (2012), WHO (2017), and USEPA (2018). This study also calculates the Heavy Metal Evaluation Index (HMEI).

The Heavy Metal Pollution Index (HMPI) (Eq. 1) uses the concentrations of heavy metals, namely Mn, Fe, Co, Ni, Cu, Zn, As, Cd, and Pb, to compute HMPI, as illustrated in Equation 1. We computed the Heavy Metal Evaluation Index (HMEI) (Eq. 2).

$$HMPI = \frac{\sum(Q_i \times W_i)}{\sum W_i} \tag{1}$$

$$HMEI = \frac{\sum_{i=1}^{n} HM_{conc}}{HM_{MPC}} \tag{2}$$

In this context, HM_conc signifies the assessed concentration of a particular heavy metal, while HM_MPC indicates its maximum allowed concentration, as established by BIS (2012), USEPA (2018), and WHO (2017). This index has a threshold value of 1: samples with an index < 1.0 are classified as appropriate, while those with an index > 1.0 are regarded as unsuitable for domestic use.

Table 1: Statistical summary of physicochemical parameters

Parameters (Units)	Statistical summary (n=30)				Guideline values
	W1 (n=6)	W2 (n=10)	W3 (n=7)	W4 (n= 7)	
	Avg	Avg	Avg	Avg	
pH	7.81	8.16	7.10	7.05	6.5-8.5[1]
Temp ()	22.4	20.45	26.4	25.6	-
EC (µS/cm)	914	548	1196	915	-
TDS (mg/L)	458	276	631	460	500[1]
T (NTU)	207	6.10	8.10	7.59	1.00[1]
TH (mg/L)	400	204	408	318	200[1]
A (mg/L)	105	191	307	228	200[1]
Ca^{2+} (mg/L)	95.7	51.4	110	81.8	75.0[1]
Mg^{2+} (mg/L)	30.4	18.5	25.8	6.1	30.0[1]
Na^{+} (mg/L)	38.7	30.8	101	66.5	50.0[2]
K^{+} (mg/L)	6.84	1.95	4.13	1.95	12.0[1]
HCO_3^- (mg/L)	146	219	370	270	-
CO_3^{2-} (mg/L)	0.178	8.14	0.004	0.50	-
Cl^- (mg/L)	88.3	33.4	146	88.4	250[1]
F^- (mg/L)	2.47	0.58	0.48	1.70	1.00[1]
NO_3^- (mg/L)	2.15	2.19	34.9	23.1	45.0[1]
SO_4^{2-} (mg/L)	173	34.6	88.9	71.4	200[1]

Statistical analysis

This study used a multivariate statistical approach to identify and classify potential sources of the measured parameters in the water samples. Due to several heavy metals being below the detection limit in some samples, correlations among the 13 physicochemical parameters were not well defined. Incorporating these unseen heavy metals would also generate ambiguities in the multivariate analysis. As a result, Brindha et al. (2020) removed seven trace elements (Fe, Co, Ni, Cu, Mo, Cd, and Pb) from the study because over 25% of their sample concentrations fell below the detection limit and utilized the remaining parameters for statistical evaluation.

RESULTS AND DISCUSSION

Physiochemical parameters

Table 1 displays the total hardness, expressed as $CaCO_3$, varied between 30 and 900 mg/L, with 93.3% of samples categorized as hard to extremely hard, which may present significant long-term health hazards, including renal complications (WHO, 2008). Significantly elevated turbidity levels ranged from 0.27 to 950 NTU, surpassing the allowed limit in 85% of all samples and 73.5% of sub-surface water samples (WHO, 2017). Furthermore, 53.3% of samples exhibited alkalinity exceeding the permissible drinking threshold (BIS, 2012; WHO, 2017). Among the samples, 48.3%, 41.7%, and 33.3% exhibited amounts of Na^+, Ca^{2+}, and F^- exceeding acceptable limits, rendering them unfit for consumption. Certain samples exhibited elevated concentrations of heavy metals Mn, As, Mo, Sr, and Ni over permissible limits (BIS, 2012; WHO, 2017). Table 2 presents the precise values.

Table 2: Statistical summary of heavy metals and toxic elements

Heavy metal	Statistical summary (n=30)			Standard values		
	Max	Min	Avg	PL	AL	R_fD[4]
Mn	1.88	bdl	0.11	0.30[1]	0.11[1]	0.01
Fe	0.15	bdl	0.10	NR[1]	0.28[1]	0.70
Co	0.01	bdl	0.005	0.05[2]	0.04[1]	0.003
Ni	0.03	bdl	0.002	NR[1]	0.01	0.02
Cu	0.01	bdl	0.001	1.50[1]	0.06[1]	0.03
Zn	2.84	0.05	0.20	14.0[1]	4.93[1]	0.30
As	0.02	bdl	0.003	0.04[1]	0.02[1]	0.0003
Sr	6.61	0.03	0.62	4.17[3]	4.17[3]	0.60
Mo	0.21	bdl	0.01	NR[1]	0.06[1]	0.005
Cd	0.0003	bdl	0.0002	NR[1]	0.002[1]	0.001
Pb	0.001	bdl	0.0005	NR[1]	0.02[1]	0.003
F	5.09	0.05	1.15	1.44[1]	0.96[1]	0.60

AL: acceptable limit (mg/L); PL: maximum allowable limit (mg/L); RfD: oral reference dose (mg/kg/day); Wi: unit mass; We express statistical values in mg/L; bdl denotes a value below the detection limit and NR indicates no result.

Assessment of Surface and Sub-surface water source

We calculated that Cd (0.50), As (0.15), and Pb (0.15) (Table 2) were the most dominant. Sharmin et al. (2020) (Table 3) used index values to classify water samples. Surface and sub-surface water source values ranged from 3.18 to 168.57, with 85% of samples rated as excellent, 11.7% as good, and 3.3% as poor to unsuitable.

While 96.7% of samples fell into the excellent and good categories, these groups included 3.5% with acidic pH, 36.2% with fluoride levels of F ≥ 1 mg/L, 84.5% with high turbidity, and 93.1% classified as hard to very hard. Therefore, these samples, despite being in the 96.7% "excellent" and "good" categories, may not be suitable for drinking. and industrial/mine effluents, which local communities do not directly use for drinking, primarily provide samples in the poor to unsuitable category. However, these contaminated waters mix with others downstream, potentially causing further degradation. Therefore, before using the water for drinking purposes, proper filtration and purification are essential.

Table 3: Classification of Surface and sub-surface water source based on HMPI, and HMEI values

Indices	Class	Category	% of samples
HMPI	<15	Low	78
	15-30	Medium	14
	>30	High	6.6
HMEI	<1	Fit	68
	>1	Unfit	30.4

The quality indices for water in the Korba area reveal that the majority of samples are of high quality. In terms of metal pollution, the Heavy Metal Pollution Index (HMPI) shows that 78% of samples have "low" pollution, 14% have "medium," and 6.6% have "high." Additionally, the Heavy Metal Evaluation Index (HMEI) indicates that 68% of samples are "fit" for use, while 30.4% are considered "unfit." (Table 3). Therefore, the overall summary suggests that while most water samples are safe, there is a significant portion with concerning levels of metal contamination.

In Table 4, the HMPI had a robust positive link with Mn and As, but HMEI demonstrated a strong positive association with Co, Ni, and Mn. These data suggest that As, Mn, Cd, Mo, Co, and Ni were the principal heavy metals responsible for the contamination of the aquatic environment in the Korba region.

The correlation matrix shows strong links between the indicators (HMPI, and HMEI) and several harmful substances found in water samples from the Korba region (Table 4). Heavy Metal Pollution Index (HMPI) at 0.55, Heavy Metal Enrichment Index (HMEI) at 0.41, Mo at 0.61, and Cadmium (Cd) at 0.60 are strongly linked to the surface and sub-surface water sources. This means that these metals may impact the overall quality of the water. HMPI has strong links to HMEI (0.67), as well as strong links to Mn (0.60) and As (0.74), which suggests that these elements have a big effect on the amount of metal pollution. HMEI exhibits the strongest link with Mn (0.93) and also demonstrates significant correlations with Co (0.61) and Ni (0.60), which are influential in heavy metal contamination. The results indicate that Mn, As, Mo, Cd, Co, and Ni are the principal elements contributing to the degradation of surface and sub-surface water sources and increased pollution indices in the region, with Mn and As notably influencing heavy metal contamination.

Table 4: Correlation matrix between toxic elements

	HMPI	HMEI
HMPI	0.98	
HMEI	0.67	0.99
Mn	0.60	0.93
Fe	0.44	0.01
Co	0.34	0.61
Ni	0.32	0.60
Cu	0.23	-0.02
Zn	-0.07	-0.04
As	0.74	0.12
Sr	-	-
Mo	-	-
Cd	0.10	0.03
Pb	-0.01	-0.02
F	-	-

CONCLUSIONS

This study conducted an assessment of surface and sub-surface in Korba coal mining and industrial regions, focusing on hazardous pollutants. Health risk analyses confirmed drinking water as a major exposure route to contaminants. Statistical methods helped find the sources of pollution by showing the main types of water molecules, including Ca-HCO_2, Ca–Mg–SO_4, and Ca–Mg–HCO_2. Sub-surface and industrial wastewater often have Ca–Mg–SO_4 tendencies. Hazardous elements like F, As, Mn, Sr, Mo, Co, Ni, and Cd were present in both the surface and sub-surface. Parameters such as turbidity, TDS, hardness, and alkalinity frequently exceeded limits, with 33.3% of samples showing high fluoride, especially near mines and factories. Elevated Na^+ (48.3%) and Ca^{2+} (41.7%) levels were also common. Toxic elements (As, Mn, Cd, Mo, Co, Ni) significantly impacted quality indices (HMPI, and HMEI). Authorities recommend prioritizing pollution control for As, F, Mo, and Mn, along with regular monitoring and safe water distribution.

Future scope of the study

Monitoring for heavy metal mining waste in the Korba Coal Mines area may pursue various viable avenues. The focus is on creating more sensitive and selective sensors to identify a wider array of dangerous substances at trace levels; hence, improving early detection capabilities. Adding seasonal and long-term monitoring to the research would also help in understanding how contamination levels change over time and finding possible patterns or risks related to mining operations. Incorporating real-time sensor data with remote monitoring systems could significantly improve the efficacy of pollution tracking, enabling ongoing evaluation and swift reaction to contamination incidents.

Furthermore, comparison analyses with alternative mining regions could corroborate findings and evaluate the usability of the proposed sensors across various environmental contexts.

Limitations of the study

Evaluations of heavy metal mining waste in the Korba Coal Mines region encounter numerous constraints. Initially, although sensors yield significant data, their detection sensitivity may be inadequate for trace amounts of specific heavy metals, potentially resulting in an underestimate of contaminants at low concentrations. The study limits its scope to specific heavy metals, potentially overlooking other harmful elements present in the mining waste.

This study did not consider temporal variables, such as seasonal changes in water contamination levels, which may affect the generalizability of the results over time. Moreover, environmental factors such as pH, temperature, and organic matter in water may compromise sensor precision, thereby impacting data reliability. Finally, focusing on a single mining area makes the results less applicable to other places, since results may be different in places with different mining methods or geochemical environments.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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