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Assessing the Impact of Coal Mining Activities on Ecosystems: A Perspective on Toxic Element Contamination in Korba District, Chhattisgarh

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ABSTRACT: This study "assessing the impact of coal mining activities on ecosystems: A perspective on toxic element contamination in Korba District, Chhattisgarh" was groundwater quality of the study area during the pre-monsoon period (April, 2021-22) through physico-chemical and heavy metal analyses. Parameters such as electrical conductivity (EC), total dissolved solids (TDS), total hardness, pH, and heavy metals (Cu, Pb, Fe, Hg, and Mo) were evaluated and compared with BIS and WHO standards. Results showed water temperature ranging from 20.63°C to 26.79°C, electrical conductivity (EC) between 396.87 µS/cm and 1916.43 µS/cm, and total dissolved solids (TDS) from 253.14 mg/L to 1226.86 mg/L. The pH values (5.42 to 6.59) revealed acidic conditions in most locations, while total hardness exceeded the BIS limit at 371.45 mg/L in some areas. Heavy metal analysis identified lead levels up to 0.119 mg/L, surpassing the permissible limit of 0.05 mg/L, posing significant health risks. Copper, iron, mercury, and molybdenum remained within acceptable ranges, with localized fluctuations. These findings highlight salinity, mineralization, and acid mine drainage impacts in the area, necessitating water treatment, continuous monitoring, and stricter environmental management to safeguard public health and ensure sustainable groundwater use.

Keywords: Groundwater quality, Physico-chemical parameters, Heavy metal, Acid mine drainage, EC and TDS.

INTRODUCTION

Coal mining, a cornerstone of energy production, plays a significant role in economic development, but it also poses severe environmental and ecological challenges. Mining activities release a variety of toxic elements, such as heavy metals, into the surrounding environment, which adversely affects soil, water, air quality, and biodiversity (Singh *et al.*, 2020). The Korba district in Chhattisgarh, often termed the "Power Capital of India," is a prime coal mining hub, hosting several large-scale mining operations. These activities have profound ecological implications due to the extensive deposition of pollutants in terrestrial and aquatic ecosystems.

The release of toxic elements like arsenic (As), lead (Pb), cadmium (Cd), and mercury (Hg) during coal extraction and processing poses long-term risks to the health of ecosystems and human populations. These contaminants can bioaccumulate in the food chain, causing severe physiological and reproductive harm to living organisms (Chakraborty & Pandey 2021). In Korba, studies have highlighted elevated levels of such elements in soil and water, threatening agricultural productivity and water quality (Kumar *et al.*, 2019).

The impact on vegetation is another significant concern, as heavy metal toxicity can impair plant growth and reduce biomass production. Furthermore, deforestation due to mining leads to habitat destruction, soil erosion, and loss of biodiversity (Mishra *et al.*, 2018). Aquatic ecosystems in the region are equally affected, with water bodies often showing signs of eutrophication and toxic element accumulation, impacting aquatic fauna and flora (Yadav & Gupta 2020).

Given these challenges, assessing the environmental implications of mining activities in Korba district is imperative for developing sustainable mining practices and ecological restoration strategies. This study aims to evaluate the extent of toxic element contamination in different ecosystems and understand its broader ecological consequences. By identifying critical areas of impact, this research can contribute to formulating targeted mitigation strategies for preserving ecological integrity in mining regions.

MATERIAL AND METHODS

The Korba district, located in Chhattisgarh, was selected as the study area due to its extensive coal mining activities. Specific sites were chosen to represent areas near mining operations, residential zones, and relatively undisturbed regions for comparative analysis.

Groundwater samples were collected from 15 locations within the study area during the pre-monsoon period (April, 2021-22) to evaluate water quality. Sampling sites were strategically chosen to represent diverse environmental conditions, including industrial zones, mining areas, and residential regions. Standard methods recommended by the Bureau of Indian Standards (BIS) and the American Public Health Association (APHA) were employed for sample collection and analysis. Physico-chemical parameters such as water temperature, pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity, and total hardness were measured using calibrated instruments like digital pH meters and conductivity meters, alongside titration techniques to ensure consistency and precision (APHA, 2017).

Heavy metal concentrations, including copper (Cu), lead (Pb), iron (Fe), mercury (Hg), and molybdenum (Mo), were analyzed using atomic absorption spectrophotometry (AAS) as per the guidelines of APHA and BIS standards. The observed values were compared against the permissible limits specified by BIS (IS 10500:2012) and WHO guidelines for drinking water quality. Statistical tools, including mean, standard deviation, and variance calculations, were used to assess spatial variations and potential contamination sources across the study area. This comprehensive methodological approach ensured a reliable evaluation of groundwater quality and its suitability for domestic and drinking purposes.

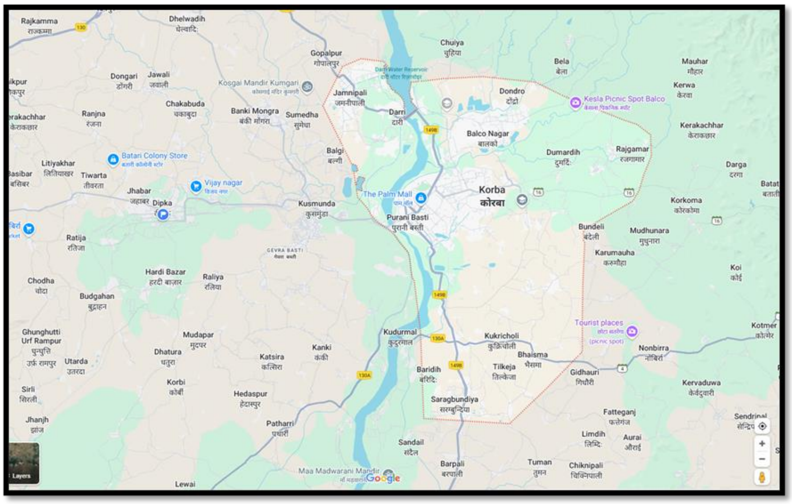

Fig. 1. Korba District Map (Google Map).

RESULTS AND DISCUSSION

A. Water Quality and Physico-Chemical Analysis

The physico-chemical parameters of groundwater samples collected during the pre-monsoon period (April, 2021-22) are summarized in Table 1. The observed parameters include water temperature, electrical conductivity (EC), pH, total dissolved solids (TDS), total alkalinity, and total hardness.

Water Temperature. The water temperature ranged from 20.63°C (L_1, Hasdev River) to 26.79°C (L_{15}, Utarda) with an average of 23.85°C. This variability can be attributed to location-specific climatic and environmental conditions. The results obtained in the present study are supported by the works of Imneisi and Aydin (2016) developed a water quality index to assess the water quality of Karacomak Dam, Kastamonu city (Turkey).

Electrical Conductivity (EC). The EC values varied widely between 396.87 µS/cm (L_9, Raliya) and 1916.43 µS/cm (L_{11}, Chakabuda), with an average of 837.21 µS/cm. Locations such as Chakabuda exceeded the BIS limit (750 µS/cm), indicating potential salinity issues affecting groundwater quality. Similar result was also found by Choden *et al.* (2020) developed ground water quality index of Saharanpur city, India and its spatial representation using Geographical Information Systems.

pH. The pH ranged from 5.42 (L_8, Vijay Nagar) to 6.59 (L_1, Hasdev River), with an average of 5.89. Most samples were slightly acidic and below the recommended range of 6.5–8.5 by BIS and WHO, suggesting the influence of acidic contaminants, possibly from mining or industrial runoff. These outcomes are consistent with findings of Krishan *et al.* (2016) evaluated the groundwater quality of Haridwar district, Uttarakhand (India).

Total Dissolved Solids (TDS). The TDS values ranged from 253.14 mg/L (L_{11}, Chakabuda) to 1226.86 mg/L (L_{13}, Balgi). The average TDS was 587.35 mg/L, with certain locations exceeding the BIS desirable limit of 500 mg/L. This indicates the presence of dissolved inorganic salts, which may affect the water's taste and potability. Similar results were also found by Choden *et al.* (2020).

Total Alkalinity and Hardness. The total alkalinity and hardness averaged 187.11 mg/L and 224.95 mg/L, respectively. Both parameters exhibited significant spatial variation. For total hardness, L_1 (Hasdev River) recorded the maximum (371.45 mg/L), surpassing the BIS limit of 300 mg/L, which classifies the water as hard and potentially unsuitable for household usage without treatment. The results obtained in the present study is in accordance with the results of Imneisi and Aydin (2016).

B. Heavy Metal Analysis

In this study Table 2 provides the concentrations of heavy metals such as copper (Cu), lead (Pb), iron (Fe), mercury (Hg), and molybdenum (Mo) in the groundwater samples.

Copper (Cu). Copper concentrations ranged between 0.198 mg/L (L_2, Dipka) and 0.302 mg/L (L_{13}, Balgi) with an average of 0.256 mg/L. All samples were within the BIS permissible limit of 1.5 mg/L, indicating minimal risk from copper contamination. This study is in accordance with the results of Kumar *et al.* (2018) assessment of heavy metals contamination of different river water of Chhattisgarh, India

Lead (Pb). The concentration of lead varied between 0.010 mg/L (L_{13}, Balgi) and 0.119 mg/L (L_2, Dipka), with an average of 0.046 mg/L. Several locations exceeded the BIS and WHO limit of 0.05 mg/L, suggesting potential health risks such as neurotoxicity, particularly in vulnerable populations. This study is in accordance with the results of Kumar *et al.* (2018) assessment of heavy metals contamination of different river water of Chhattisgarh, India and Similar results were reported by Kumar and Shah (2004).

Iron (Fe). Iron levels were observed between 0.146 mg/L (L_{15}, Utarda) and 0.190 mg/L (L_6, Hardibazar). Despite the average concentration of 0.168 mg/L being below the BIS limit of 0.3 mg/L, localized increases could impact water quality due to staining and metallic taste. This study is in accordance with the results of Kumar *et al.* (2018) ; Zhou *et al.* (2006) estimated water quality by applying Multivariate Statistical Methods in the North-western New Territories, Hong Kong.

Mercury (Hg) and Molybdenum (Mo). Mercury concentrations remained minimal (<0.002 mg/L), with all samples complying with the BIS and WHO standards. Molybdenum concentrations also adhered to permissible limits, with an average value of 0.005 mg/L. This study is in accordance with the results of (Zhang *et al.*, 2009) assessing the water quality of Daliao river basin.

C. Comparative Assessment and Implications

Comparison of the data with BIS and WHO standards highlights several concerns. High electrical conductivity, TDS, and heavy metal contamination (notably lead and iron) at specific locations signal potential anthropogenic impacts, including mining, agricultural runoff, and industrial activities. The acidic pH levels in several locations further suggest acid mine drainage as a contributing factor.

D. Recommendations

- **Water Treatment:** Installation of treatment systems, such as reverse osmosis or ion exchange, is recommended in affected areas.
- **Regular Monitoring:** Continuous monitoring of groundwater quality, especially in mining and industrial zones, is essential.
- **Mitigation Measures:** Implementing stricter environmental controls and remediation strategies to manage contamination sources is crucial.

Table 1: Water Quality and physico-chemical analyses of groundwater samples of study area collected during Pre-monsoon (April, 2021-22).

Sr. No.	Water Body Location	Water Temp. (°C)	Electrical conductivity (EC)	Hydrogen ion (pH)	Total dissolved solids (TDS) (mg/L)	Total alkalinity (mg/L)	Total hardness (mg/L)
1.	L_1 (Hasdev River)	20.63	467.42	6.59	948.82	338.19	371.45
2.	L_2 (Dipka)	24.25	495.57	5.71	619.45	160.82	315.66
3.	L_3 (Kusmunda)	22.14	1272.25	5.52	299.63	126.93	139.48
4.	L_4 (Surakachhar)	25.42	870.53	5.46	316.45	109.41	143.85
5.	L_5 (Gevra Mine Area)	24.74	1490.87	5.87	814.68	224.43	247.72
6.	L_6 (Hardibazar)	25.41	469.53	5.58	556.47	156.52	267.93
7.	L_7 (Bhilai Bazar)	26.36	1024.48	5.53	953.89	342.64	327.42
8.	L_8 (Vijay Nagar)	21.42	814.56	5.42	300.25	122.71	79.63
9.	L_9 (Raliya)	21.74	396.87	5.96	655.63	211.85	299.52
10.	L_{10} (Kuchaina)	22.53	858.63	5.97	521.42	190.42	159.86
11.	L_{11} (Chakabuda)	23.84	1916.43	5.85	253.14	97.69	79.74
12.	L_{12} (Batari)	23.71	733.82	6.14	549.75	194.78	279.36
13.	L_{13} (Balgi)	24.55	507.96	5.81	1226.86	186.63	271.93
14.	L_{14} (Jawali)	24.23	732.74	6.43	469.49	207.75	255.47
15.	L_{15} (Utarda)	26.79	506.45	6.52	324.36	135.87	135.29
	Max	**26.79**	**1916.43**	**6.59**	**1226.86**	**342.64**	**371.45**
	Min	**20.63**	**396.87**	**5.42**	**253.14**	**97.69**	**79.63**
	Ava	**23.85**	**837.21**	**5.89**	**587.35**	**187.11**	**224.95**
	SD	**1.77**	**419.55**	**0.37**	**279.45**	**70.98**	**90.40**
	Variance, σ^2	**3.12**	**176024.05**	**0.14**	**78094.52**	**5038.02**	**8171.86**
Comparison of groundwater quality of Drinking water standards by BIS and WHO	**Indian Standard (BIS)**	—	**750.00**	**6.5-8.5**	**500.00**	**200.00**	**300.00**
	WHO Standard Desirable Limit	—	**400.00**	**7.0-8.0**	**1000.00**	**200.00**	**100.00**

Table 2: Heavy metal analyses of groundwater samples of study area collected during Pre-monsoon (April, 2021-22).

Sr. No.	Water Body Location	Copper Cu (mg/L)	Lead Pb (mg/L)	Iron Fe (mg/L)	Mercury Hg (mg/L)	Molybdenum Mo (mg/L)
1.	L_1 (Hasdev River)	0.211	0.117	0.162	0.001	0.010
2.	L_2 (Dipka)	0.198	0.119	0.160	0.002	0.002
3.	L_3 (Kusmunda)	0.238	0.019	0.162	0.000	0.003
4.	L_4 (Surakachhar)	0.301	0.079	0.170	0.001	0.004
5.	L_5 (Gevra Mine Area)	0.221	0.018	0.180	0.000	0.008
6.	L_6 (Hardibazar)	0.301	0.115	0.190	0.001	0.007
7.	L_7 (Bhilai Bazar)	0.301	0.016	0.180	0.002	0.009
8.	L_8 (Vijay Nagar)	0.266	0.017	0.180	0.001	0.001
9.	L_9 (Raliya)	0.292	0.015	0.170	0.001	0.002
10.	L_{10} (Kuchaina)	0.231	0.016	0.150	0.001	0.005
11.	L_{11} (Chakabuda)	0.211	0.102	0.150	0.000	0.006
12.	L_{12} (Batari)	0.242	0.013	0.160	0.001	0.010
13.	L_{13} (Balgi)	0.302	0.010	0.180	0.000	0.003
14.	L_{14} (Jawali)	0.289	0.013	0.175	0.001	0.004
15.	L_{15} (Utarda)	0.235	0.014	0.146	0.001	0.005
	Max	**0.302**	**0.119**	**0.190**	**0.002**	**0.010**
	Min	**0.198**	**0.010**	**0.146**	**0.000**	**0.001**
	Ava	**0.256**	**0.046**	**0.168**	**0.001**	**0.005**
	SD	**0.037**	**0.044**	**0.013**	**0.001**	**0.003**
	Variance, σ^2	**0.001**	**0.002**	**0.000**	**0.000**	**0.000**
Comparison of groundwater quality of Drinking water standards by BIS and WHO	**Indian Standard (BIS)**	**1.50**	**0.05**	**0.3**	**0.001**	**0.01**
	WHO Standard Desirable Limit	**1.30**	**0.05**	**0.3**	**0.002**	**0.01**

CONCLUSIONS

The study highlights significant spatial variations in groundwater quality within the study area, with several locations exceeding BIS and WHO permissible limits for key parameters. High electrical conductivity, TDS, and total hardness indicate salinity and mineralization issues, while acidic pH levels suggest impacts from acid mine drainage and industrial activities. Heavy metal contamination, particularly elevated lead concentrations, poses health risks, necessitating immediate attention. Although copper, iron, mercury, and molybdenum levels were generally within acceptable limits, localized fluctuations emphasize the need for regular monitoring. These findings underscore the importance of implementing effective water treatment solutions and environmental management strategies to ensure safe and sustainable groundwater use.

FUTURE SCOPE

The study on coal mining's impact in the Korba district highlights several avenues for future research and interventions. Key areas include:

1. Sustainable Mining Practices: Developing techniques to minimize toxic element release.

2. Ecological Restoration: Implementing strategies like reforestation and soil stabilization to restore affected ecosystems.

3. Toxic Element Monitoring: Creating advanced models to assess the behavior of contaminants in the environment.

4. Human Health Impact: Linking environmental contamination to health outcomes in local communities.

5. Policy Development: Formulating region-specific regulations and enhancing community involvement.

6. Renewable Energy: Exploring cleaner energy alternatives to reduce coal dependency.

7. Climate Change Adaptation: Investigating strategies to mitigate mining's greenhouse gas emissions.

Conflict of Interest. None.

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