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Heavy metal contamination in river systems of upper Assam, India: A review

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Abstract

Heavy metals are toxic, persistent, and non-biodegradable pollutants that pose severe ecological and human health risks when released into aquatic ecosystems. Acid mine drainage (AMD), arising from the oxidation of sulfide minerals during coal and polymetallic mining, is a major source of heavy metal contamination in rivers. In Northeast India, particularly Upper Assam and adjoining Nagaland, coal mining has significantly impacted river systems such as Dikhow, Disang, Burhi Dihing, Dhansiri, Tirap, and Jhanji. This review focuses on the Dikhow River, where a sudden water color change and fish mortality event in April 2022 raised concerns of AMD-induced pollution, while also synthesizing available literature on other Upper Assam rivers. Findings reveal that cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), and lead (Pb) concentrations consistently exceed permissible limits, especially during the monsoon when AMD inflow is highest. The ecological implications include fish kills, loss of aquatic biodiversity, bioaccumulation in the food chain, and reduced water usability. This review highlights the urgent need for improved monitoring, metal fractionation studies in sediments, and the adoption of advanced remediation strategies including bioremediation using sulfate-reducing bacteria (SRB). Sustainable management of AMD-impacted watersheds is critical for protecting river health and dependent communities in Upper Assam.

Keywords: Acid Mine Drainage; Heavy Metals; Dikhow River; Upper Assam Rivers; Coal Mining; Bioremediation; Environmental Pollution

1. Introduction

Heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), copper (Cu), and iron (Fe) are of major environmental concern due to their toxic, persistent, and bio-accumulative nature. Once released into the environment, they cannot be degraded and instead accumulate in sediments and aquatic food chains [1]. Mining, particularly coal mining, is a key source of heavy metal pollution. Acid mine drainage (AMD), formed when sulfide minerals (e.g., Pyrite, FeS_2) oxidize upon exposure to oxygen and water, generates sulfuric acid which leaches metals into waterways [2].

In India, coal mining in Nagaland, Meghalaya, and Upper Assam contributes significantly to AMD generation [3]. The rivers of Upper Assam — Dikhow, Disang, Burhi Dihing, Dhansiri, Tirap, and Jhanji — all receive AMD runoff from nearby coalfields, degrading their water quality. The April 2022 incident of sudden green coloration and fish mortality in the Dikhow River (Sivasagar District, Assam) underscores the urgency of addressing AMD impacts. This paper aims to review heavy metal contamination and AMD impacts in the Dikhow River and compares findings with other AMD-impacted rivers in Upper Assam. It also provides some mitigation measures that can be effective in dealing with AMD contamination.

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1.1. Study Area

The rivers reviewed here are major tributaries of the Brahmaputra:

- *Dikhow River*: Originates in Zunheboto, Nagaland; flows through Sivasagar district, Assam; length 255.8 km [4].
- *Disang River*: Rises in the Patkai hills of Nagaland and flows into Sivasagar district, Assam.
- *Burhi Dihing River*: Originates in Arunachal Pradesh, flows through Tinsukia and Dibrugarh districts; impacted by coal mining and oil drilling.
- *Dhansiri River*: Originates in Nagaland and flows through Golaghat district, Assam.
- *Tirap River*: Originates in Changlang, Arunachal Pradesh, flows into Assam; drains coal mining zones.
- *Jhanji River*: Originates in Mokokchung, Nagaland, flows through Sivasagar district.

These rivers are critical for fisheries, agriculture, and local livelihoods, making AMD-induced contamination a serious concern.

2. Methodology

This review compiles water quality and heavy metal concentration data from published studies [4, 5, 6, 7, 8]. Parameters include pH, DO, EC, turbidity, sulphates, and heavy metals (Cd, Cr, Cu, Fe, Pb, Mn, Zn). Seasonal variations (pre-monsoon, monsoon, post-monsoon) were considered where available. Figures and comparative tables were prepared to illustrate AMD impacts across river systems.

3. Review of Experimental Findings

3.1. Acid Mine Drainage in Dikhow River

AMD studies at Naginimora (upper reach, Nagaland) revealed highly acidic drainage (pH 2.4), very high EC (8610 μmhos/cm), and sulphate concentrations (413 mg/L) (Gogoi & Saikia, 2019). Seasonal monitoring showed low pH (5.53 ± 0.25), low DO (5.2–6.0 mg/L), and high turbidity (143.8 NTU) during monsoon. CWC (2019) reported Cd, Cr, Cu, Fe, Pb exceeding permissible limits at Sivasagar and Bihubar WQ stations. These anomalies can be closely linked to the April 2022 mass fish kill.

3.2. Comparative Heavy Metal Contamination in other rivers of Upper Assam

Table 1 Heavy Metal Concentrations in Major Upper Assam Rivers (mg/L)

River	Major Source of AMD / Pollution	Cd (mg/L)	Cr (mg/L)	Cu (mg/L)	Fe (mg/L)	Pb (mg/L)	Reference
Dikhow	Coal mining (Nagaland)	0.02–0.05	0.08–0.15	0.12–0.22	1.8–4.5	0.10–0.28	CWC, 2019; Gogoi & Saikia, 2019
Disang	AMD inflow from Nagaland mines	0.01–0.03	0.06–0.12	0.08–0.18	1.5–3.8	0.09–0.24	Sarmah et al., 2020
Burhi Dihing	Coal mining, oil drilling	0.02–0.04	0.07–0.13	0.10–0.20	2.0–4.2	0.11–0.30	Baruah et al., 2018
Dhansiri	Coal & industrial effluents	0.01–0.02	0.05–0.10	0.09–0.15	1.2–3.5	0.08–0.20	Sharma et al., 2017
Tirap	Coal mining (Nagaland-Arunachal)	0.02–0.06	0.09–0.18	0.11–0.25	2.2–5.0	0.12–0.33	CWC, 2019
Jhanji	Coal mining runoff	0.01–0.03	0.06–0.11	0.07–0.14	1.3–3.6	0.09–0.21	Sarmah et al., 2020

Note: Values compared against BIS drinking water standards (Cd ≤0.003, Cr ≤0.05, Cu ≤0.05, Fe ≤0.3, Pb ≤0.01 mg/L) show that all rivers exceed safe limits.

3.3. Seasonal Influence

- Monsoon: Highest metal loads due to AMD wash-off, erosion, and runoff (TDS and COD peak; DO lowest).
- Pre-monsoon: Lower turbidity but AMD trickling still contributes to elevated Fe and sulphates.
- Post-monsoon: Partial recovery but metals persist in sediments, posing long-term risks.

3.4. Ecological and Human Health Impacts

Fish kills (Dikhow 2022; Burhi Dihing, multiple years) are linked to DO depletion and metal toxicity. pH reduction and DO depletion during monsoon disrupts aquatic life cycles. Cd and Pb can accumulate in fish tissues, thereby threatening food safety. Persistent metal fractions may remobilize under changing pH/DO conditions leading to sediment contamination.

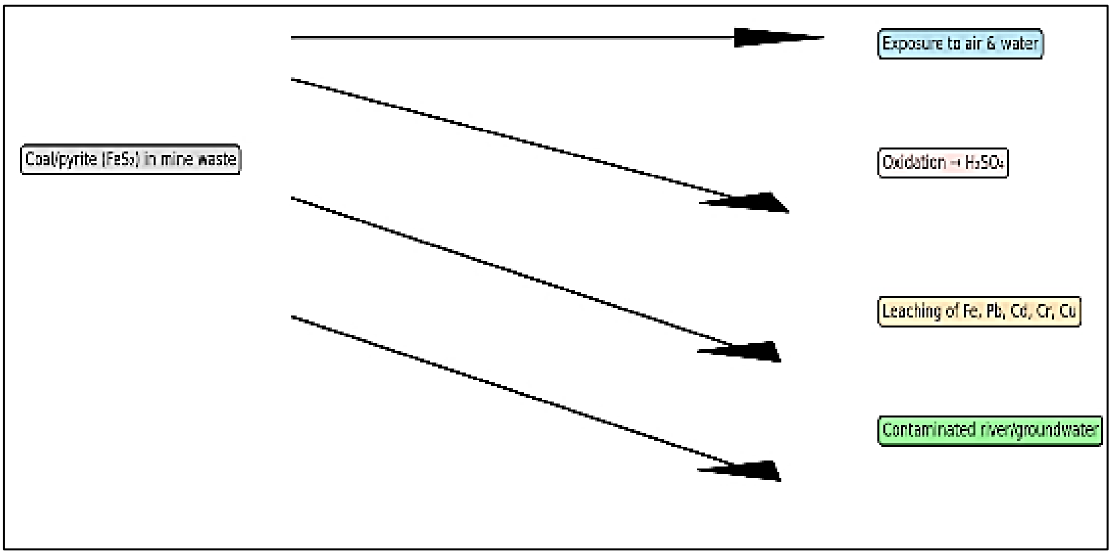

Figure 1 Acid Mine Drainage Formation and Impact

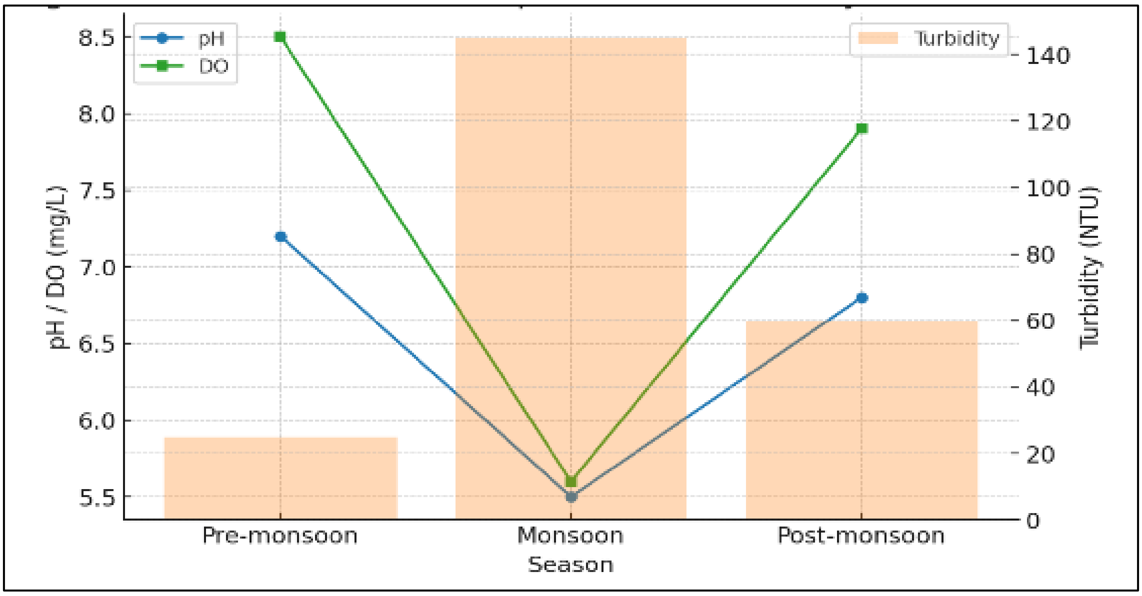

Figure 2 Seasonal variation of pH, DO, and turbidity in Dikhow River (Based on data of Gogoi and Saikia, 2019)

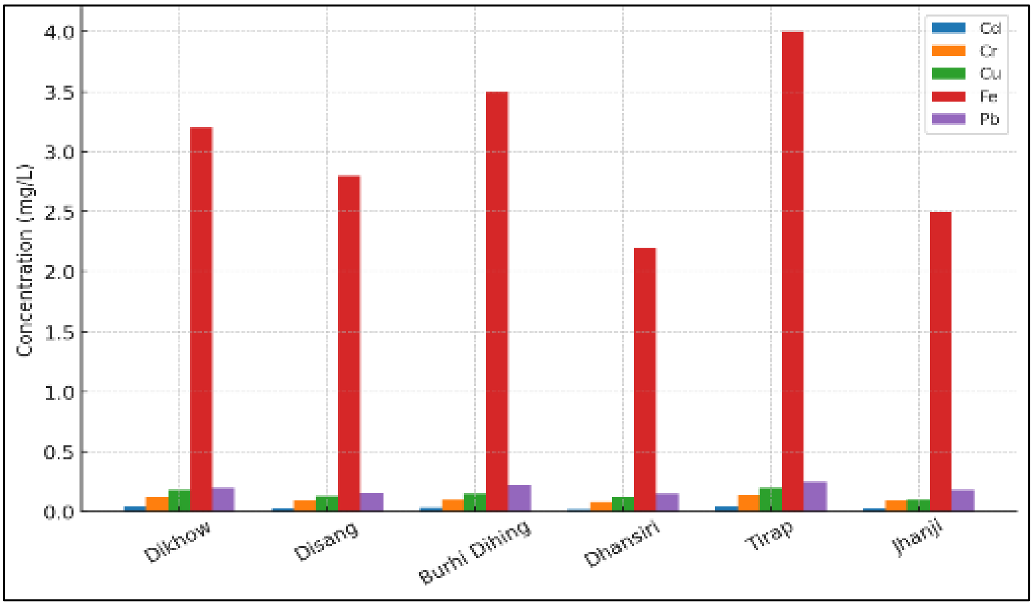

Figure 3 Heavy metal concentrations in major rivers of Upper Assam (Based on CWC, 2019)

4. Mitigation Strategies

Mitigation of AMD-related heavy metal pollution requires a combination of preventive, active, and passive approaches [9, 10, 11].

- **Preventive Measures at Source**: Proper management of coal mine overburden is necessary to minimize pyrite exposure. There must be construction of impermeable covers and diversion drains to prevent infiltration of rainwater into mine-tailings. Moreover, backfilling of abandoned mines is essential to reduce AMD generation.
- **Active Treatment Techniques**: Chemical precipitation technique such as addition of lime, limestone, or alkaline reagents can be handy to neutralize acidity and precipitate metals. Synthetic resins, activated carbon, and low-cost natural adsorbents (e.g., biochar, zeolite, rice husk ash) can be used for metal removal by Ion Exchange and Adsorption. Membrane technologies like Reverse osmosis, nanofiltration, and electrodialysis for selective metal removal can also be undertaken. Electrocoagulation and electroflotation for AMD neutralization and metal recovery can be a useful electrochemical treatment procedure.
- **Passive Treatment Systems:** Vegetated systems (e.g., Typha, Phragmites) that facilitate natural filtration and metal sequestration can be effective in the area if wetlands are constructed. Anoxic Limestone Drains can reduce acidity by dissolving limestone under oxygen-poor conditions. Furthermore, Permeable Reactive Barriers that use reactive materials (limestone, organic compost) to immobilize metals in groundwater can also be fruitful.
- **Bioremediation Approaches**: Certain Sulfate-Reducing Bacteria (SRB) can be induced to promote anaerobic conditions to convert sulphates to sulfides, precipitating metals as insoluble sulfides. Microbial Fuel Cells that harness microbial activity can be used to simultaneously treat AMD and also generate bioelectricity. Algal and Fungal Biosorption method that use microalgae and fungi to capture and immobilize heavy metals can also prove helpful.
- **Policy and Community-Level Interventions**: Regular monitoring should be done by CWC/CPCB and state pollution control boards, especially during monsoon. Enforcement of strict effluent discharge standards in coal mining areas is a mandatory measure. Along with this, community awareness and engagement in river health monitoring programs is the need of the hour. Finally, incorporation of AMD remediation in regional water management policies should be strictly enforced.

5. Conclusion

Heavy metal contamination in the Dikhow River and other rivers of Upper Assam is primarily driven by AMD from coal mining in Nagaland and adjoining regions. Seasonal monitoring reveals elevated Cd, Cr, Cu, Fe, and Pb concentrations beyond permissible limits, particularly during the monsoon. Ecological effects such as fish kills, biodiversity loss, and food chain contamination underscore the urgency of intervention. This review emphasizes integrated monitoring, advanced remediation technologies, and sustainable watershed management as critical steps for mitigating AMD pollution in Upper Assam rivers.

Compliance with ethical standards

Disclosure of conflict of interest

The author declares no conflict of interest.

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Author short biography

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