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Coal Mine Generated Pit Lakes in Abandoned Mining Areas in Raniganj Coal Field: Characteristics and Ecological Significance

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ABSTRACT

Coal mine-generated pit lakes in the Raniganj Coal Field (RCF) are a unique and complex ecological phenomenon resulting from historical mining activities. These pit lakes, formed by the intersection of open-pit mines with the water table, exhibit diverse characteristics and play a significant role in post-mining landscapes. This review explore the morphological features, water quality, ecological significance, and restoration strategies associated with these pit lakes and the findings contribute to a deeper understanding of their importance and inform sustainable management practices.

Keywords Pit lakes, Raniganj coal field, Water quality, Restoration.

INTRODUCTION

Mining activities have a profound impact on landscapes, altering their topography, land use and ecological dynamics. One remarkable consequence of mining is the formation of pit lakes, which occur both in active and abandoned mining areas. These pit lakes are created when open-pit mines deepen and intersect the water table. The Raniganj Coal Field (RCF) in West Bengal, India, has a rich history of coal mining dating back to the nineteenth century. Over the years, hundreds of open pits were excavated, resulting in permanent landscape changes. In this context, this review explore the characteristics and ecological significance of coal mine-generated pit lakes in the Raniganj Coal Field and focuses on several key themes. The characteristics of these pit lakes vary widely, influenced by factors such as the type of mine, environmental conditions and climate. Pit lakes serve as unique geoecological environments. They can potentially be used for various purposes, including water storage, recreation, wildlife habitat and geological heritage sites. Monitoring the water quality of these pit lakes is crucial and understanding seasonal variations and the potential for changing water quality over time is essential for sustainable management. Despite their origin in industrial activities, pit lakes can support biodiversity. They become secondary habitats for threatened species. The restoration of pit lakes can enhance ecological sustainability, providing refuges for aquatic and terrestrial organisms. Evidence-based restoration, informed by detailed studies, is essential for maximizing biodiversity in these freshwater habitats. Evaluating the long-term benefits and potential uses of these pit lakes is critical. Sustainable management practices should consider

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local knowledge, community engagement, and the changing nature of these restored habitats.

Characteristics of coal mine generated pit lakes

Coal mining has played a crucial role in various regions, including the Raniganj Coal Field in India, one of the oldest and largest coal fields in the country, with mining activities beginning in the late 18th century. Pit lakes differ from natural lakes in their physical structure, particularly due to their higher depth-to-surface area ratio. This is quantified by the percent relative depth, which measures the maximum depth of a lake as a percentage of its width, assuming a circular shape. Natural lakes typically have a lesser relative depth than pit lakes (Redondo-Vega *et al.* 2021) which facilitates stratification and leads to significant variations in chemical properties at different depths. The presence of sub-toxic or anoxic layers in these lakes can greatly impact their chemical and biological characteristics, influencing potential remediation efforts.

Pit lakes often have limited catchment areas, resulting in minimal surface water inflow, which can help prevent further degradation of water quality from exposed geologies. However, if the exposed geologies do not pose a threat, it may be advantageous for these lakes to capture clean surface water, although small catchments can restrict this. The water quality in pit lakes can vary widely, particularly regarding acidity, salinity, hardness and metal concentrations, largely influenced by the hydrology and geochemistry of the catchment area (Mondal *et al.* 2023a, Mondal *et al*. 2015). For instance, pit lake water may become acidic due to the oxidation of iron-rich geologies, leading to Acid Mine Drainage (Dutta *et al.* 2020) which can be harmful to aquatic life. Additionally, pit lake waters that are acidic and saline can negatively impact nearby ground water resources and ecosystems, such as wetlands, by allowing contaminated plumes to spread over large distances down-gradient. The chemical makeup of a pit lake is influenced by the alkalinity of the surrounding ground water, the composition of the wall rocks, and the amount of runoff from the land (Castendyk *et al.* 2015, Kemanga *et al.* 2024).

Overview of Raniganj Coal Field's abandoned mine sites

Raniganj Coal Field is a prominent coal mining area in India that has experienced extensive mining activity over the years, located primarily in the Asansol and Durgapur subdivisions of Paschim Bardhaman district in West Bengal, India. The Raniganj Coal Field extends into neighboring districts such as Birbhum, Bankura, Purulia and even Dhanbad district in Jharkhand. It has a rich history, being the first coal mining area in India, with operations dating back to 1774 when John Sumner and Suetonius Grant Heatly of the British East India Company discovered coal near Ethora. The early mining efforts were somewhat haphazard, but regular mining began in 1820 under the agency house of Alexander & Co Later, Prince Dwarkanath Tagore acquired the collieries, and for much of the 19th and a significant part of the 20th century, Raniganj Coal Fields was the country's major coal producer (Manna and Maiti 2014). The coalfield covers an area of 443.50 square kilometers and boasts a total coal reserve of 49.17 billion tonnes. These reserves are distributed across the Indian states of West Bengal and Jharkhand. In terms of reserves, it ranks as the second largest coalfield in India (Manna and Maiti 2014). The coal seams in the Raniganj Coal Field can be categorized into two blocks: Raniganj measures: This block includes areas like Raniganj-Pandaveswar, Kajora, Jhanjra, Bankola, Kenda, Sonepur, Kunustoria, Satgram, Sripur, Sodepur, and partly Salanpur. Barakar measures: Covering Salanpur and Mugma.

Unfortunately, the coal field also faces challenges. Scores of abandoned coal mines dot the landscape, leading to defaced topography and safety risks. When these mines collapse, the land above them gives way, causing cracks in houses, sinking fertile agricultural lands, and drying up wells. The Raniganj Coal Field stands as a testament to both the legacy of coal mining and the need for sustainable land use practices.

Water quality and environmental impact of Raniganj pit lakes

The opencast coal extraction method in India often

results in voids or pits that are eventually filled by surface runoff and groundwater seepage, forming pit lakes. These pit lakes have unique physical properties compared to other water bodies. While they can serve as potential water reservoirs, their water quality and environmental impact need careful assessment. A study conducted in the Raniganj Coal Fields area of West Bengal aimed to monitor the water quality of pit lakes seasonally. The researchers analyzed physico-chemical parameters of water samples using standard methods. The mean pH value recorded was 7.65. The pit lakes generally exhibited an alkaline nature. A significant positive correlation was observed between hardness and chloride. Mine waters showed compositional differences with seasonal changes, indicating their capability to change over time (Mondal *et al.* 2023a, Mondal *et al.* 2023b).

The major environmental impacts of coal mining activities on surrounding areas and human health have been well-documented. Pit lakes, although unique, can pose challenges due to water quality issues. While they may not always be suitable for direct use, they can still serve as resources for recreation, fisheries, and wildlife habitat. Their long-term benefits lie in providing water for industrial activities and potentially mitigating reliance on natural systems. Despite potential water quality challenges, studies suggest that pit lakes in the Raniganj area have the capability for natural restoration. Soil quality and water quality were found to be good, supporting rich growth of plant species both in aquatic and terrestrial habitats. These lakes can sustain biodiversity and meet basic human needs, especially during times of water scarcity. Sustainable interventions can further enhance their ecological value (Manna and Maiti 2014).

Research on coal mine-generated pit lakes has focused on various aspects, including water quality, ecological dynamics, remediation strategies and socio-economic implications. Here is a brief overview of some fundamental studies and findings in this area: Water quality assessment of coal mine pit lakes have been the focus of several studies, including those conducted by Pal *et al.* (2013), Mondal *et al.* (2015), Mondal *et al.* (2023a). These studies have examined the water quality parameters of pit lakes formed by coal mining activities. The findings indicate that such pit lakes often exhibit high acidity levels, elevated concentrations of heavy metals, and increased turbidity due to the leaching of minerals and chemicals from surrounding rocks and mine wastes. The studies highlight the importance of implementing effective water management strategies to mitigate the environmental impacts associated with pit lakes. Shinde *et al.* (2012) provided an overview of commonly analyzed physico-chemical parameters in pit lakes and discussed the impact of mining activities on water quality and ecological implications. The composition of mine fluids is exceedingly complicated and exhibits significant variability. These substances exhibit a range of pH levels, including near neutrality, alkalinity, moderate acidity and strong acidity. Dutta *et al.* (2020) conducted a study that revealed the presence of very acidic mine drainages in certain coal mines located in North Eastern India. These drainages were discovered to include trace elements deemed highly unsuitable for consumption due to their unwanted properties. The potability of water is compromised, rendering it unsuitable for consumption. Treatment and disinfection would be necessary for domestic utilization, whereas mine water can be employed for the purpose of irrigation. Singh *et al.* (2018) conducted a study on the environmental geochemistry and quality evaluation of mine water in the Jharia Coal field, India. The findings of the study indicate that the mine water generally meets the allowed quality standards and can be considered suitable for irrigation purposes in the majority of situations. Nonetheless, the elevated salt levels, residual sodium carbonate content, and Mg-Na ratio impose limitations on its appropriateness for irrigation purposes in certain locations. Water quality analysis plays a crucial role in protecting the environment and human health in pit lakes. It provides a comprehensive understanding of the chemical, physical and biological characteristics of the water, enabling decision-making and effective management strategies. Additionally, establishing a water quality index (WQI) for pit lakes simplifies the assessment of complex data, aids in decision-making, and supports the overall management and protection of these water bodies. The WQI serves as a valuable tool for summarizing water quality information and raising awareness about potential

issues among stakeholders, including policymakers, regulatory bodies, local communities, and industry professionals. By tracking changes in water quality over time, the WQI can provide early warning signs of deteriorating conditions and guide the prioritization of management and remediation efforts. Furthermore, the publication of WQI results can raise public awareness about the importance of maintaining good water quality and the potential consequences of neglecting it. Overall, water quality analysis and the use of a WQI are essential for safeguarding the environment and human well-being in pit lakes. McCullough *et al.* (2020), and Vandenberg *et al*. (2022) conducted research on various remediation techniques for coal mine-generated pit lakes. These techniques, such as liming, aeration, and the use of constructed wetlands, aimed to improve water quality and restore ecological functions. The findings of these studies highlighted the potential of these techniques in mitigating the environmental impacts of pit lakes and enhancing their sustainability.

Biodiversity and habitat creation in post-mining landscapes

Post-mining landscapes, once scarred by industrial activities, have the potential to transform into valuable habitats for biodiversity. Freshwater habitats in post-mining areas can serve as secondary habitats for threatened species. Restoration efforts should be evidence-based, especially given the global decline in freshwater biodiversity. Studies on restoration effects are scarce, limiting habitat efficiency. Restoration approaches included technical reclamation, spontaneous succession and their combination. Key beneficial features for conservation were smaller water bodies, heterogeneous littoral vegetation, gradual banks, absence of fish, sun-exposed water surfaces and surrounding forests (Kolar *et al.* 2021).

Informal local activities play a crucial role in providing diverse habitats and enhancing biodiversity within post-mining sites. Active engagement with the community and utilization of local knowledge improve ecological interpretation and future management (Rich *et al.* 2015). Restored habitats after mining can develop higher monetary value than pre-mining conditions. These habitats become refuges for biodiversity in cultural landscapes (Brus *et al*. 2020). Challenges related to ecosystem disturbances caused by mining activities and structural changes are discussed. Post-mining landscapes are expected to provide essential ecosystem services (Gerwin *et al.* 2023).

Restoration strategies for coal mine generated pit lakes

Restoration strategies for coal mine generated pit lakes in the Raniganj Coal Field area are essential to mitigate environmental degradation and promote ecological balance. These strategies include significant measures such as implementing proper land reclamation techniques, promoting revegetation and reforestation efforts, and ensuring effective water management practices to improve water quality and maintain sustainable ecosystems. By restoring the disturbed landscape through land reclamation techniques, such as contouring and grading, the physical structure of the pit lakes can be reshaped to ensure stability and prevent erosion. At the same time, promoting revegetation and reforestation efforts in the surrounding areas can help restore native plant species and enhance biodiversity. Additionally, implementing effective water management practices is crucial to address issues of water pollution and ensure the sustainability of the pit lakes. By implementing these restoration strategies, the coal mine generated pit lakes in the Raniganj Coal Field area can be transformed into functional ecosystems that provide habitat for aquatic organisms, capture and store carbon, regulate water flow, and support local communities through tourism and recreation.

Case studies: Successful reclamation of coal mine pit lakes

In the Raniganj Coal Field area, there are some studies which are related to the reclamation of coal mine pit lakes in the Raniganj Coal Field (RCF). These examples highlight effective strategies for restoring and repurposing these post-mining ecosystems. A study focused on the Raniganj Coal Field examined the defaced topography resulting from opencast mining activities. Proper reclamation measures were proposed to mitigate the impact on the landscape immediately after mining

(Manna and Maiti 2014). Researchers explored the environmental consequences of coal mining in the Raniganj Coal Field region. This area falls under the command of Eastern Coal Fields Limited (ECL). A comprehensive investigation in the Sonepur-Bazari opencast coal mining area (within the Raniganj Coal Field) analyzed the impacts of coal mining on various capitals (financial, physical, human, natural, and social). The study shed light on how these capitals influence rural livelihood practices (Mondal and Mistri 2021). Surface mining significantly alters land use and land cover (LULC) in the Raniganj Coal Field. Researchers assessed spatio-temporal changes in mining areas, considering soil, water and landholders. Understanding these changes is crucial for sustainable management (Patra *et al.* 2022).

Ecological significance of pit lakes in abandoned mining areas

Coal mine generated pit lakes in abandoned mining areas in Raniganj Coal Field have significant ecological significance. These pit lakes provide habitat for diverse aquatic species and can serve as important breeding grounds for fish and other aquatic organisms. They also contribute to the overall biodiversity of the region and can support a variety of plant and animal life. Furthermore, pit lakes in coal mining areas can contribute to the hydrological cycle by storing and releasing water. This can help in regulating water levels and maintaining groundwater recharge in the surrounding areas. Another ecological significance of pit lakes in coal mining areas is their potential for water treatment and remediation. Pit lakes have the ability to naturally filter and purify water, as they can act as passive treatment systems for contaminants present in the surrounding environment. Additionally, the unique characteristics of pit lakes can create niches and habitats for specialized organisms that are adapted to the specific conditions found in these environments. These organisms may have unique ecological roles and contribute to the overall functioning of the ecosystem.

Future prospects for pit lakes in Raniganj coal field

Each pit lake ecosystem is unique, and unexpected ecological interactions may arise. Adaptive management and ongoing research are essential. Addressing these challenges requires inter disciplinary collaboration, scientific research and a commitment to sustainable practices. With thoughtful planning, pit lakes can become valuable assets for future generations. The future prospects for pit lakes in the Raniganj Coal Field are uncertain, but there is potential for their utilization in various ways. One possibility is to use the pit lakes for recreational purposes, such as boating and fishing, which can boost tourism in the area and provide economic opportunities for the local community. Additionally, the pit lakes could be used for water storage and irrigation purposes, addressing the need for agricultural potential in the region. Another potential future prospect for pit lakes in the Raniganj Coal Field is their use for water treatment and purification. Furthermore, if proper management strategies are implemented, pit lakes in the Raniganj Coal Field could also serve as important ecological habitats, attracting diverse wildlife and contributing to biodiversity conservation efforts.

CONCLUSION

The coal mine-generated pit lakes in the Raniganj Coal Field represent a dynamic interface between human intervention and natural processes. These lakes vary in depth, shape and water quality. Understanding these variations is essential for effective management and utilization of these aquatic ecosystems. Despite their industrial origin, pit lakes serve as valuable ecological niches. They support aquatic and terrestrial biodiversity. Their potential for habitat creation, water storage, and recreational use underscores their significance. The restoration of pit lakes can enhance biodiversity. These habitats become refuges for native species. Strategies should focus on promoting natural succession and creating favorable conditions for aquatic life. Evidence-based restoration approaches and community engagement are crucial for maintaining ecological balance and long-term sustainability of these pit lakes.

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