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Exploring the ecological impact of coal mine generated Pit lakes: a brief review

Saikat Mondal*

Department of Zoology, Raghunathpur College, Purulia - 723133 (India)

Abstract

Coal mining operations have historically left behind large open pits that fill with water, forming what are known as pit lakes. These pit lakes are known to have significant ecological impacts, both positive and negative, on the surrounding environment. This review aims to provide an overview of the ecological effects associated with coal mine-generated pit lakes and highlights the importance of understanding these impacts for effective environmental management. These water bodies can support diverse biological communities, including fish, invertebrates, and aquatic plants. Pit lakes can serve as refuges for species that may have been displaced by mining activities and can contribute to the overall biodiversity of the region. Additionally, pit lakes can act as reservoirs for water storage, particularly in arid regions, and can potentially provide water resources for various purposes, including agricultural or industrial use. However, negative impacts of pit lakes cannot be overlooked. One of the primary concerns is water quality degradation. The high levels of dissolved minerals and heavy metals in pit lake water can result in acid mine drainage, leading to reduced water quality and the potential for toxic effects on aquatic life. Pit lakes may also experience altered hydrological regimes, leading to changes in water levels, flow patterns, and sedimentation rates, which can disrupt natural ecosystems and affect the surrounding terrestrial habitats. Understanding and mitigating the ecological impacts of coal mine-generated pit lakes is crucial for effective environmental management. Strategies such as water treatment and remediation techniques can be employed to minimize the release of contaminants and improve water quality. Additionally, implementing measures to maintain or restore natural hydrological regimes can help mitigate negative impacts and enhance the ecological functioning of pit lakes.

Key words : Coal mining, pit lake, biodiversity, ecosystem.

*Assistant Professor,

Coal mining has long been a vital industry, providing a major source of energy for countries around the world. However, the extraction of coal often leaves behind large excavated pits, commonly known as pit lakes, which have significant ecological implications. The extraction of coal and other minerals has left behind these water-filled holes, which can have both beneficial and detrimental effects on the surrounding ecosystem. Because of the underlying geological conditions and the presence of groundwater, pit lakes may have unsatisfactory water quality[8,20,26,30]. Public worry has been sparked by worries about poor water quality, however restored pit lakes are excellent instances of revitalized recreation and culture[32]. Additionally, and frequently in harsh conditions, scientists use pit lakes as a platform to investigate new species, metabolic processes, biogeochemical processes, and interactions within and between trophic levels[8-11]. However, in comparison to other inland aquatic ecosystems, the environmental stigma attached to pit lakes, the lack of interdisciplinary scientific collaboration, and the unpublished data owned by the mining industry have probably hindered scientific advancements in pit lake research[4]. This article aims to delve into the ecological impact of coal mine-generated pit lakes, shedding light on the various ways in which these unique ecosystems can affect surrounding habitats, water quality, and biodiversity. By examining the positive and negative aspects, we can gain a comprehensive understanding of the overall ecological dynamics associated with pit lakes.

Formation of Pit lakes :

Pit lakes are defined as water-filled depressions that form when open-pit mines are abandoned. They are created when mining activities expose underground aquifers or when rainwater accumulates in the excavated pits. The formation process involves a series of hydrological and geological factors, such as the topography of the area, local climate conditions, and mining techniques employed. Understanding how pit lakes are formed is crucial for predicting their behavior and implementing appropriate measures to address their environmental impact. Glimpses of some pit lakes formed due to open cast mining in the Raniganj coal filed area is provided in Figure 1.

Basic characteristics of pit lakes :

Coal mine generated pit lakes, also known as mine voids or open pits, exhibit certain characteristic features that distinguish them from natural lakes or water bodies. Understanding these basic characteristics is essential for comprehending the unique ecological dynamics and management considerations associated with these anthropogenic water bodies. Pit lakes are created as a result of open-pit or underground coal mining operations. After the extraction of coal or other minerals, the excavation site is left as a void, which is eventually filled with water from various sources such as rainfall, surface runoff, groundwater seepage, or even deliberate filling.

The size and shape of pit lakes can vary significantly, depending on the scale of the mining operation and the characteristics of the geological formation. They can range from relatively small, shallow depressions to large, deep lakes covering extensive areas. The shape of pit lakes is typically irregular, reflecting the contours of the excavated area.

Pit lakes are primarily filled with water from external sources. In some cases, these water bodies may be connected to nearby rivers, streams, or aquifers, receiving inflows and outflows. The water quality of pit lakes can be influenced by the characteristics of the source water and the surrounding geological formations. Pit lakes can exhibit considerable depth, often reaching depths greater than natural lakes in the surrounding area. The depth of pit lakes can vary across different areas of the lake, resulting in stratification—layers of water with different physical and chemical properties. Thermal stratification, for example, can lead to variations in temperature and dissolved oxygen profiles within the lake. Over time, pit lakes can undergo ecological development, with the establishment of aquatic plant and animal communities.

Figure 1. Glimpses of some coal mine generated pit lakes.

Positive impacts :

Water storage and conservation :

One of the primary positive impacts of pit lakes is their ability to store and conserve water. These lakes can act as reservoirs, capturing rainfall and runoff, thereby contributing to the local water supply. This not only benefits nearby communities but also helps in mitigating water scarcity issues during dry seasons.

Habitats for aquatic Life :

Pit lakes often provide new habitats

for aquatic organisms. Over time, these water bodies can support a diverse array of plant and animal life, including fish, amphibians, and invertebrates. Such ecological niches can promote biodiversity and create opportunities for the establishment of unique and specialized species communities.

Recreational and aesthetic value :

Once established, pit lakes can become valuable recreational spaces, offering opportunities for boating, fishing, and other water-based activities. Additionally, these lakes can enhance the aesthetic appeal of the surrounding landscape, attracting nature enthusiasts and providing a visually pleasing environment.

Negative Impacts

Water Quality Concerns

Pit lakes can pose significant challenges to water quality due to the leaching of minerals and other contaminants from the surrounding geological formations. The exposed rocks and soils can release heavy metals, acidity, and other pollutants into the water, resulting in potential ecological damage and limiting the usability of the water for various purposes. All inhabited continents have pit lakes, although it's difficult to pinpoint their precise number[6]. Pit lakes' ability to contaminate surface and ground waters because of their poor water quality is one of the main issues surrounding them[34]. Environmental issues can exacerbate the economic hardships faced once local mining operations end when pit lakes are located close to communities[25]. In addition, the amount of water in pit lakes is a problem, particularly in light of climate change. Water from the nearby catchment region may be diverted when pit lakes are filled and kept at a constant level in drought conditions[27]. Additionally, the creation of a new lake in a landscape that would typically lack surface water can lead to long-term declines in groundwater, potentially at a higher rate compared to naturally formed lakes[23]. However, excessive water can also be problematic. Due to their small catchment areas, large pits are unlikely to fill quickly through surface runoff and rainfall under "normal" precipitation conditions[19]. In areas prone to typhoons and seasonal flooding, the entry of large volumes of water into pit lakes can lead to uncontrolled discharges, resulting in infrastructure damage, economic losses, social stress, and changes in downstream water quality[28]. The water quality and hydrology of pit lakes can have significant and widespread environmental impacts. Elevated levels of contaminants in the water can adversely affect aquatic organisms' health, disrupt ecological processes, and pose risks to human health if the water is used for drinking or irrigation. Changes in hydrological patterns can also impact the connectivity of water systems, potentially causing downstream effects on rivers, wetlands, and other natural habitats.

Zhao *et al*.,s[35] study from 2023 looked at how coal mining activities affect surface ecosystems and groundwater systems. The study probably looked into how mining operations affected biodiversity, ecological functioning, and water quality. The results highlighted the possible threats that changing groundwater flow patterns and habitat changes pose to human communities and the ecosystem. In order to limit adverse effects, the study

made recommendations and emphasized the significance of sustainable mining operations.

Masood *et al.*,[21] conducted a second study that examined the effects of natural carbon mineralization on the geochemical development of coal-based aquifers in Punjab, Pakistan. The study evaluated the effects of carbon sequestration on groundwater quality and investigated the mechanisms by which carbon is naturally stored in geological formations. To comprehend carbon mineralization in the aquifers, field surveys, lab tests, and geochemical analysis were carried out. The results showed how naturally occurring carbon mineralization lowers the carbon content of groundwater and offered guidance for the sustainable management of aquifers that are fueled by coal. The use and workings of a unique biofilter system for extracting Fe2+ and Mn2+ from acidic mine wastewater were covered by Hu *et al.*,[15] in 2022. Water quality increased as a result of the system's successful oxidation-based removal of these metal ions. The study highlighted how well the biofilter can handle acidic wastewater that contains Fe2+ and Mn2+. The biofilter system was recommended as a cost-effective and environmentally benign way to lessen the negative environmental effects of mining wastewater due to the proposed mechanism, which included microbial-mediated oxidation processes. Jiang *et al.*,[16] looked into the sources and amounts of dissolved inorganic carbon (DIC) in groundwater in East China's coal mining regions using hydrochemistry and 13C studies. The study looked at the causes of DIC and how coal mining operations relate to it. The study's findings indicated that various carbon sources contributed differently to groundwater DIC, which may have implications for understanding how coal mining affects groundwater quality. The integrated approach provided insights into managing environmental concerns in coal mining regions and underscored the importance of interdisciplinary methods for studying groundwater dynamics.

Disruption of Terrestrial ecosystems :

The creation of pit lakes often involves extensive land disturbance, including the removal of vegetation and alteration of topography. This disruption can negatively impact terrestrial ecosystems, leading to habitat loss for terrestrial wildlife and changes in the hydrological regime of nearby streams and wetlands. Large-scale open-pit coal mining frequently damages land by seriously degrading terrestrial ecosystems[31]. Surface vegetation is destroyed as a result of the process, which produces a significant volume of abandoned rocks and soil that take up large land areas. As a result, the amount of flora in the area is steadily declining[17,33]. As a major carbon sink in terrestrial ecosystems, vegetation is essential to maintaining both the global carbon balance and the stability of the climate[1,13].

Long-term ecological sustainability :

Pit lakes have the potential to become long-term liabilities if not properly managed. Without appropriate measures for water treatment and ongoing monitoring, these lakes can become stagnant, leading to decreased water quality, loss of biodiversity, and increased risks to both human health and the environment.

Reducing the negative impacts of coal mine-generated pit lakes :

Reducing the negative impacts of coal mine-generated pit lakes on society and the overall environment requires a comprehensive management approach that addresses various aspects of water quality, ecological stability, and community engagement. Here are some management techniques that can be employed to minimize the negative impacts of pit lakes:

Water quality monitoring and treatment :

The implementation of a comprehensive water quality monitoring program is essential to proactively identify and address potential issues. Regular monitoring of key parameters like pH, dissolved oxygen, nutrient levels, and contaminant concentrations enables early detection of water quality degradation. Adhering to higher water quality standards increases the versatility of the pit lake for future uses, while lower standards restrict its potential applications. It could be required to treat the water through pre-rehabilitation measures in order to preserve the greatest amount of flexibility for future use. However, alternative permanent solutions may be difficult to achieve, especially for remote or developing communities. Active treatments like liming, "pump-and-treat" systems, or in situ bioreactors have limited long-term sustainability[2,4,12]. Converting the pit lakes into bioreactors can temporarily address water quality issues when reasonable investments are possible[12,24]. To address certain issues with water quality, such as pH correction, sediment control, and nutrient management, it is imperative to use efficient water treatment methods.

Ecological restoration and Habitat enhancement :

Enhancing the ecological value of pit lakes can help mitigate the negative impacts on biodiversity and habitat loss. This can involve initiatives such as re-vegetation of surrounding areas, creation of artificial habitats, and introduction of native plant and animal species. Restoring riparian zones and establishing buffer areas can help reduce sediment and nutrient runoff, improving water quality and providing additional habitat for wildlife.

Wetland creation and enhancement :

Constructing or enhancing wetlands within and around pit lakes can serve as effective natural filters, improving water quality by removing pollutants and excess nutrients. Wetlands also provide valuable habitats for a diverse range of plant and animal species. These constructed or restored wetlands can be designed to mimic natural wetland processes, promoting biodiversity and acting as a buffer zone between the pit lake and surrounding areas.

Community engagement and education :

Engaging with local communities and stakeholders is crucial for effective pit lake management. Providing information, conducting public consultations, and involving communities in decision-making processes fosters a sense of ownership and encourages responsible use and stewardship of pit lakes. Public education programs can help raise awareness about the ecological importance of pit lakes and promote sustainable practices among nearby residents and recreational users.

Long-term management and monitoring :

Establishing long-term management

plans and continued monitoring is vital for the sustained health of pit lakes. Regular inspections, water quality assessments, and ecological monitoring should be conducted to detect any changes and ensure the effectiveness of management strategies. Adaptive management approaches allow for adjustments and improvements based on new information and changing conditions.

Closure and rehabilitation Planning :

The biodiversity is specifically and seriously threatened by mining activity. But mining can also provide funds for other livelihood options that may eventually stop the loss of biodiversity[5,14,18,22,29]. Planning for pit lake closure and rehabilitation must be incorporated into mining operations from the outset. This means creating plans to deal with the pit lake's long-term management and possible usage after mining. The pit lake can move safely and sustainably to a new stage, such recreational or conservation use, by putting in place appropriate closure and restoration procedures. This strategy reduces possible hazards to the environment and society. Pit lakes created by coal mines can have their negative effects reduced and turned into sustainable, advantageous landscape features that benefit both the environment and society with careful planning, ongoing monitoring, and community involvement[5,14,18,22,29].

This review has shed light on the ecological impact of coal mine-generated pit lakes. It is evident that these water bodies, formed as a result of mining activities, pose significant challenges to ecosystems and biodiversity. The extraction of coal mining contribute to direct pressures on biodiversity, affecting the delicate balance of natural habitats. Additionally, the presence of metal contaminants in mine-degraded soils and extremely acidic environments further exacerbates the ecological impact. The review highlights the urgent need for remediation and ecological restoration measures to mitigate the negative effects of pit lakes. Efforts should focus on developing comprehensive strategies that address the characteristics and challenges specific to each pit lake. These strategies should consider factors such as water quality, soil contamination, and the establishment of suitable vegetation. Moving forward, it is crucial to continue research and monitoring efforts to deepen our understanding of the ecological impact of coal mine-generated pit lakes. This includes investigating the long-term consequences of these water bodies on surrounding ecosystems and identifying effective remediation techniques. In addition, interdisciplinary collaborations among scientists, engineers, policymakers, and local communities are essential for developing innovative solutions and implementing best practices for the ecological management of pit lakes. This can involve knowledge sharing, technology transfer, and capacity building initiatives. Ultimately, by addressing the ecological impact of coal mine-generated pit lakes and implementing sustainable practices, we can strive towards a more balanced and resilient coexistence between mining activities and the natural environment.

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Competing interest

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