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PIT LAKES AS SUSTAINABLE POST-CLOSURE INTERVENTIONS FOR OPEN-CAST COAL MINES IN THE INDIAN CONTEXT

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ABSTRACT

Coal is a pivotal link in balancing India's increasing energy demands as well as infrastructure development, catering to about three-fourths of the country's power generation. Ninety four percent of the coal produced in India is mined from more than 200 open cast mines in various parts of the country. While open-cast coal mines also have positive spinoffs for the local population in terms of infrastructure creation, jobs and business opportunities during the operation period, their impacts on the local ecology have been well documented. The changes to ecology during operative and post-closure phases demonstrate the need for improved mine closure planning so that the adverse impacts of opencast mining can be controlled in a more scientific manner compared to current mining practices in India. With the introduction of Section 20A in the Mines and Minerals (Development and Regulation) Act in January 2015, Parliament has empowered the Central Government to issue policy directives for "*promoting restoration and reclamation activities so as to make optimal use of mined-out land for the benefit of the local communities.*" Pit lakes are artificial waterscapes developed by filling-up of the voids with water via natural and/or artificial recharge. The sustainability of these ecosystems, however, is under investigation owing to the complexity of their interactions across the long-term geological and biological realms. In India, such approaches are quite novel and there is a need to evolve scientific measures to adopt pit lakes as sustainable alternatives to backfilling with excavated soil. The present study is an assessment of the efforts and plans of utilising pit lake ecosystems in India as creative post-closure solutions for open-cast mining. Using examples of environmental statuses of the existing pit-lake ecosystems in India, analyses of their potentials as sustainable alternatives for backfilling has been explored. For the first time, the study will provide an understanding of the desired criteria to be planned while creating pit lakes. Using data from a compilation of scientific investigations, the impact of factors such as the mine closure planning, diversion of stream-flows, adoption of natural recharge, and the need for technological interventions for stabilising the ecosystem flows and conservation in these ecosystems will be closely examined. Critical design factors such as lake depth, management of the monimolimnion, biological interventions, balancing the lake leakance versus seepage to aquifers, long-term contaminant transport etc. will be discussed. Finally, the need for policy changes to design the final mine void as part of a self-sustained ecosystem to serve the needs of the local communities will also be discussed with the idea of imparting long-term sustainability to these ecosystems.

Keywords: Open-cast mine closure, Pit lakes, Water management, Ecosystems, Sustainability

1.0 INTRODUCTION

In the recent years, the idea of adopting sustainable coalmining operations have received tremendous attention (e.g. Hilson and Basu, 2003) with the perspective of holistic approach gaining dominance over a post-closure scenario evaluation. As a result, these practices are being adopted starting from the planning phases through the operative and post-closure phases with varying degree of successes. While a number of post-closure land management options are available for consideration, a popular post-closure management strategy has been the conversion of mine voids into 'pit lakes' (e.g. Soni et.al., 2014; Vandenberg et. al., 2017).Pit lakes are artificially evolved landscapes resulting from the back-filling of mine-voids post-closure with water through natural or artificial recharge. These artificially created ecosystems have the capacity to function as water reservoirs or recreational hotspots, which can also help to generate sustainable revenue at local levels (McCullough and Lund, 2006; Soni and Wolkersdorfer, 2016).

However, the successes or failures of the pit lake approach are dependent upon several factors including natural and socio-cultural as illustrated from many global studies on coal mining (e.g. Faircheallaigh, 2003; Frank et. al. 2010; Australian Mine Closure report, September 2016). The problems with the use of pit lakes for other purposes such as industrial water allocation or groundwater recharge units is still not well-understood due to the possibility of contamination with mine leachates in the anoxic bottoms, contaminant transport and groundwater salinization over time. In order to achieve the sustainable use of these ecosystems, it is important to monitor their quality over time and immediately extend scientific and technological interventions in the event of ecological disasters as a part of the active ecosystem management (Doupé and Lymbery, 2005; Australian Mining Practises report, 2011; Australian Mine Closure report, September 2016; Kodir et.al., 2017).

The major debates on the sustainable use of the ecosystem services of pit lakes revolve around multitudes of stakeholder perspectives. These include those of the following groups of stakeholders in pit lake creation and usage:

1. Local communities (as primary users),
2. Coal-mine owners,
3. Environmentalists form a part of Civic Society and bring the social and scientific perspectives of sustainability to this issue,
4. Regulatory authorities who have to approve the creation of such pit lakes as a part of the mine closure process,
5. Administrators who are involved in ensuring that the interests of the local communities are protected during the creation and operation of pit lakes.

However, in the present study, we focus on the aspects of science and technology for landscape management and sustenance of pit lakes in the Indian context. The need for robust mine-closure plans for India were highlighted in recent times, keeping the creation of a self-sustained ecosystem at the heart of such planning (Srikanth and Nathan, 2018). Srikanth and Nathan (2018) have highlighted that it is important for coal-mine owners to consider the restoration of mined landscapes to enhance the ecological and socio-economic services of the restored areas which will ensure the long-term sustainability of the mined-out areas in the interest of the local communities.

With the "State" as a trustee of the natural resources, the Ministry of Coal and the Ministry of Environment, Forest and Climate Change (MOEF&CC) are responsible for effective oversight of the mine closure process in India to ensure that the environmental impacts of mining are ameliorated and the mined-out land is rehabilitated to ensure a self-sustaining system is created post closure. This is critical not only to prevent environmental degradation but also to ensure that the mined-out land can be utilised for the welfare of the local communities in tune with the Sustainability Development Goals (SDG) adopted by India in 2015. The backfilling with overburden may not always be a viable option for mines with high strip ratios. It might be impossible to achieve total backfilling mainly due to the low availability of the overburden as has been illustrated with open-cast mines elsewhere (e.g. Latrobe Valley, Victoria, Australia; Monash University report, 2010). Therefore, the legal and regulatory framework for coal mines in India in relation to mine-closure permit the creation of pit lakes as long as the mined-out area is restored to a self-sustaining system and is also beneficial to the local communities. The plan for allowing natural seepage and precipitation to flood the mine voids with water to create pit lakesmay offer significant opportunites for sustainable development of the mined landscapes, although the challenges towards achieving complete or partially complete rehabilitation are also proportionally higher. These can be overcome by incorporating the design criteria for pit lake construction and maintenance. Figure 1 shows the processes associated with coal-mining highlighting the phases and scope for creating pit lakes as new resources at the end-phase of mine operation.

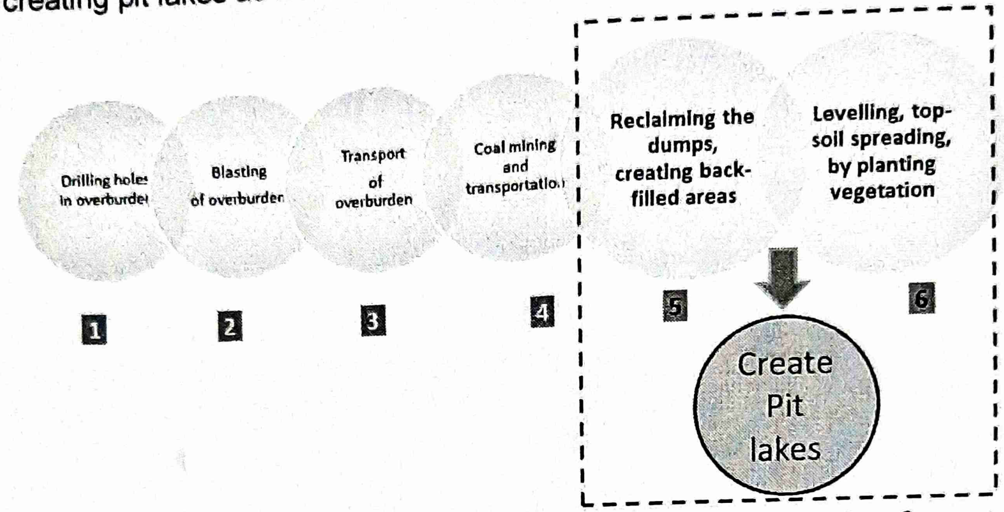

Figure 1: Scope for creating pit lakes as observed through the lifecycle of open-cast coal mining processes; during the Stages 4 and 5, pit lakes can be envisaged as useful environmental and sustainable alternatives to backfilling with sediments.

With advancements in the technology of coal mining in India, the increase in the amount of land excavated are also relatively higher, which is likely to result in pits or voids of huge sizes which cannot be backfilled without excavating already vegetated overburden dumps thereby creating further environmental impacts even after the coal reserves are exhausted. Under these circumstances, the creation of pit lakes as a sustainable alternative for the mine void deserved due consideration in the interest of local communities which are in many cases deprived of reliable access to water, particularly in the parched coalfields of India. The discussion is continued forward with a note on the sustainability of open-cast mining in India.

1.2 OPEN CAST MINING IN INDIA

While mining operations have positive economic impacts on the local area in terms of infrastructure development and provision of employment and business opportunities for the local population, adverse impacts of coal mining on the ecology of the local area are also well known. The changes in the ecosystem of the region are particularly significant in the case of opencast coal mines which account for about 94 percent of the coal produced in India. Consequent to the adoption of mine closure guidelines by the Ministry of Coal (MOC) in 2009, MOC has approved mine closure plans for 583 coal/lignite mines/projects till March 31, 2019, of which 237 are opencast coal/lignite mines in operation today. These mine closure plans also form a part of the mining plans that provide vital inputs to the Environmental Impact Assessment (EIA) documents submitted to the Ministry of Environment, Forest and Climate Change (MOEF&CC) during the environmental clearance process.

As per the current (2013) MOC Guidelines, "*final mine closure activities will start towards the end of the mine life and continue even after the coal reserves are exhausted to create a self-sustained ecosystem.*" When a mine owner defaults on his obligations towards final mine closure for any reason, the Government would not have any access to the Owner's equipment and/or personnel but would have to hire (at market prices) all resources required to successfully carry out final mine closure. Therefore, the owner of each opencast coal mine in India is required to deposit an amount of Rs. 6 lakhs per hectare of the total project area (in August 2009 prices) on an annual basis (to be escalated using the notified wholesale price index) into an escrow account as a pre-requisite to the grant of the statutory mine opening permission by the Coal Controller who functions under the MOC. The funds so generated are to provide security to cover the cost of mine closure in case the mine owner fails to complete the approved closure activities.

The total amount (including accumulated interest) deposited in the 557 escrow accounts operated by the Coal Controller is only Rs. 7552 Crores as on March 31, 2019. While the existing practice of identification of activities of mine closure and their cost estimates is only indicative in nature. The escrow amount is calculated at a flat rate irrespective of the actual cost of mine closure to create a "*self-sustained eco-system*" which varies from mine to mine. However, an analysis of mine closure plans of select opencast coal mines in India indicates this amount may be grossly inadequate to cover the cost of final closure of 235+ opencast coal/lignite mines in operation that are covered by these escrow agreements.

2.0 PIT LAKES – A BRIEF INTRODUCTION

2.1 STRUCTURE AND ENVIRONMENTAL CONSIDERATIONS

Schulz et.al. (2010) considered five major factors that controlled the geomorphology of the pit lakes as shown in Figure 2. Apart from these, other factors such as the quantity and the initial quality of the filled-in water, the status of the groundwater, the existing levels of groundwater recharge and extraction, the amount of dilution from precipitation etc. also contribute to the ecological status of the pit lakes. For example, if the water filled-in is drawn from a river or a stream, likely to be polluted, the trophic status of the pit lake ecosystem can be quite low. It is important to consider if the basement rock characteristics of pit lakes, which impart different slope characteristics to the system (e.g. Satyanarayana et. al., 2017) and hence would impact their depositionary and circulatory functions.

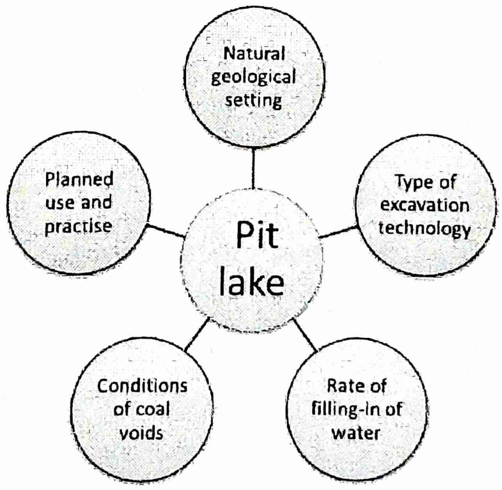

Figure 2: Factors controlling the environmental setting of pit lakes (adapted from Schulz et al. 2010).

The ecological structure of pit lakes depends on the stratification of the different layers of water based on the pH, temperature, concentration of dissolved solutes as well as the mineral and gaseous phases saturated in the water (e.g. Ramstedt et. al., 2003). These in turn determine the quality of the water and the dynamicity of interacting zones within the lake systems. A typical pit lake (Figures 3a and b) is situated within a stepped-up void, which would impart the lake, a staircase bathymetry with steep slopes (Blanchett and Lund, 2017). The inclination of the walls could be an important factor while considering the circulatory characteristics of the lake. This factor can impact the formation and propagation of the eddiesas well as the mixing characteristics from the surface to the base, facilitating a "double diffusion" and chemical stratification of the pit lakes (Stevens and Lawrence, 1998).

A layer below the epilimnion on the surface (~14-16 m from the epilimnion), known as the "Chemocline" represents the maximum degree of change in the chemical properties of the lake waters (i.e. chemical stratification) and divides the lake systems into distinct chemical zones. Pit lake systems can develop either primary or both primary and secondary chemoclines within their ecological structures based on the mixing characteristics (Campbell and Torgersen, 1980). The development of these chemoclines determines the ecosystem processes that bestow "meromixis" to the lake systems (i.e. loss of circulatory overturn at a certain depth that can lead to development of a highly dense lower layer), making them stagnant water systems at some point in time.

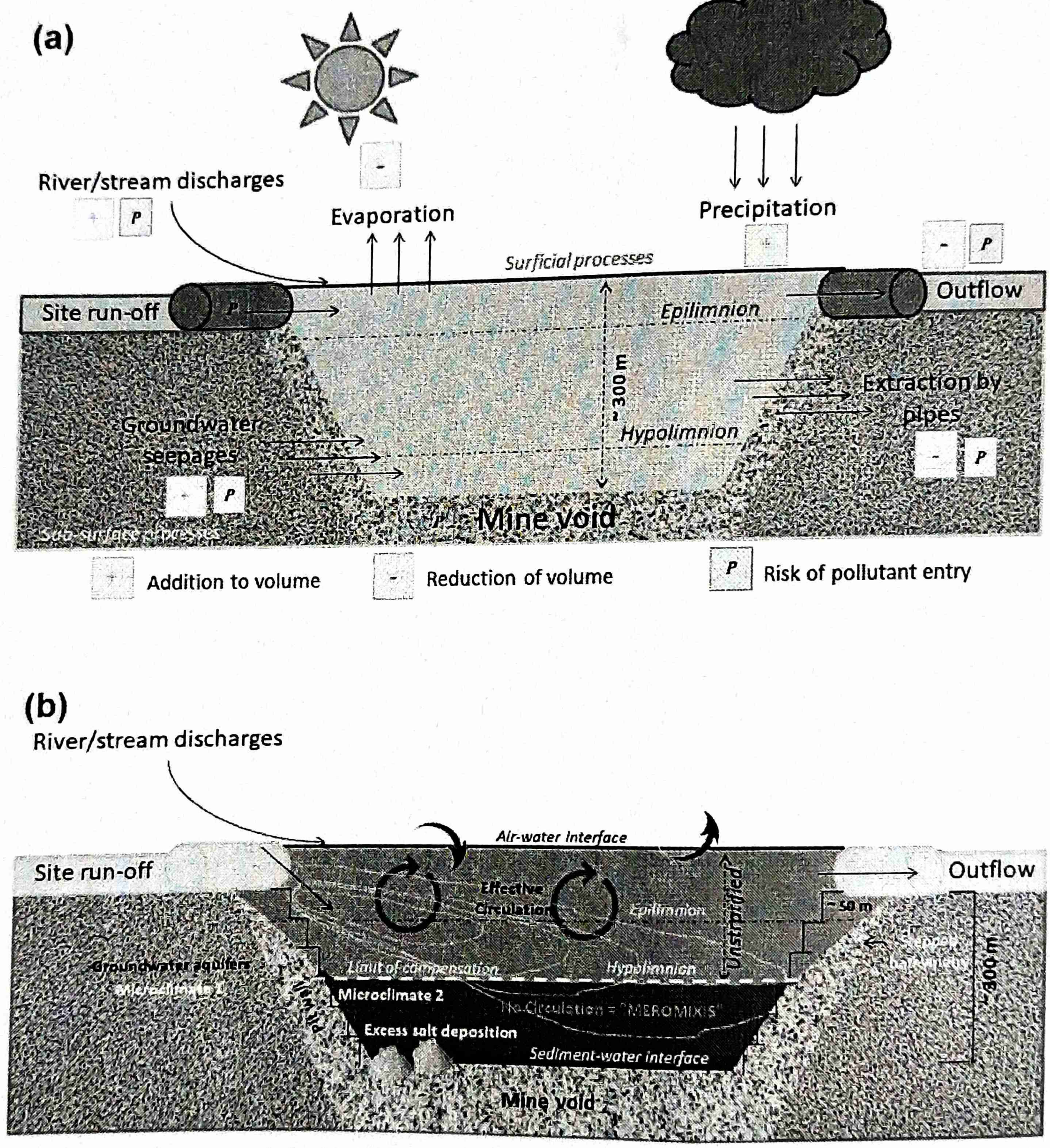

Figure 3: The environmental structure of pit lakes illustrating (3a) the possible systems of exchange and (3b) the circulatory processes that will drive the ecosystem functions.

It has been illustrated that the chemocline forms the immediate boundary between the mixolimnion exhibiting the oxidising environment and the reducing environment of the monimolimnion (Campbell and Torgersen, 1980). Such boundary layers vary in the widths ranging between 10 – 100 m and convey the passage of crucial ionic components such as iron across the chemocline. These reactions usually lead to the development of extensively reducing or adequately mixed conditions below the chemocline, leading to either an increase or decrease in the amounts of degradation products in the monimolimnion. Such ecosystem processes directly contribute to the changes in the water quality and aquatic biodiversity over a period of time

2.2 DESIGN CONSIDERATIONS FOR PIT LAKES

As discussed in the preceding section, pit lake ecosystems in India, in their natural states of evolution are characterised by their stepped bathymetry with steep slopes, variable storage volumes, usually a high depth-to-surface water spread ratio, fragile and displaceable banks and sparse vegetation at the phase of resource creation. In order for their transformation into self-sustaining ecosystems, it is clear that the maintenance of the pit lakes requires active civil, mechanical and ecological interventions at different phases of operation and maintenance as summarised in Figure 4 anddetailed in the following sections.

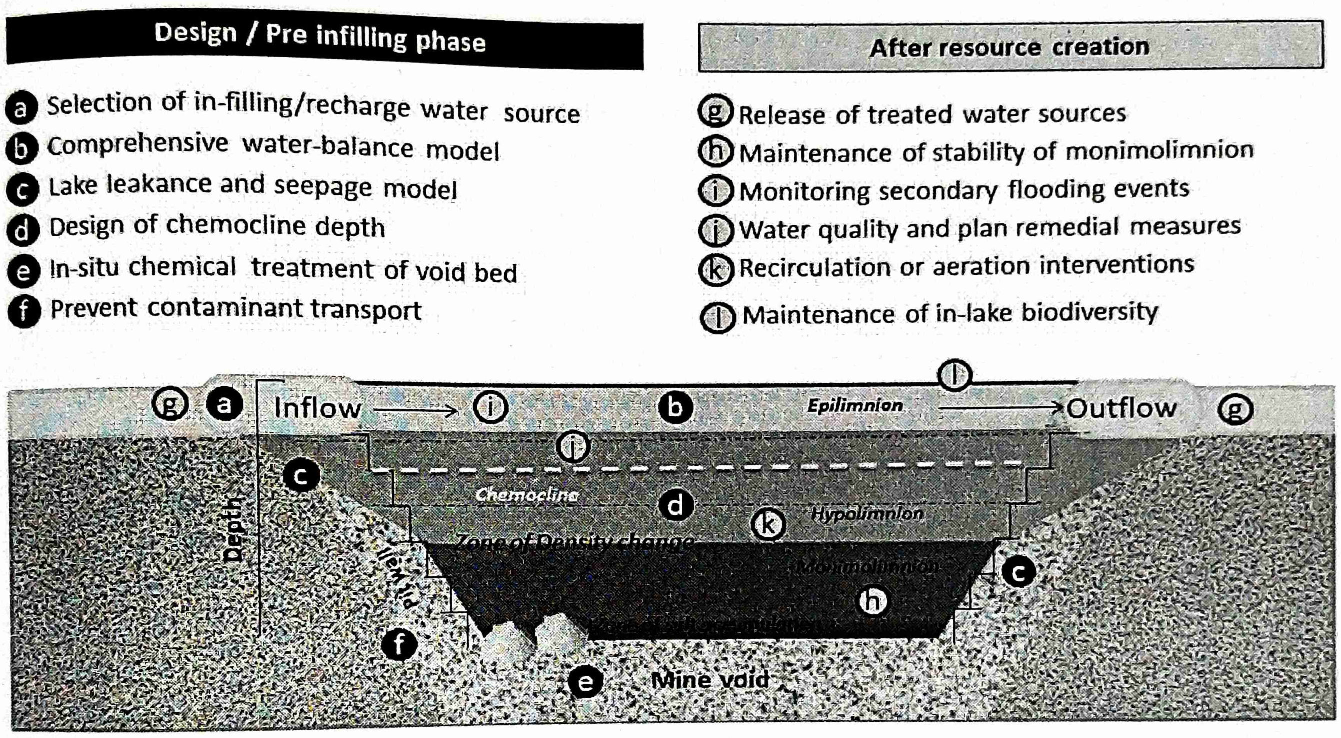

Figure 4 : Major technical considerations in designing pit lakes as sustainable mine-closure alternatives

From the Indian context, the diversity of the local geology and the subsurface characteristics requires a closer look at the nature of the substratum (e.g. Shevenell et al., 1999). Post-mining operations including the filling-in of the mine void with the overburden tend to favour the long-term rehabilitation of the pit lake system. Designing the depth for dumping of the overburden, keeping in mind appropriate depth-to-surface area ratios favours the rise of aquifer levels and increases the stability of the pit lake substratum over the long term (Foley et. al., 2012). Further, factors such as the hydraulic gradient between the lake and the groundwater as well as the hydraulic conductivity of the pit wall slope determine the magnitude of the freshwater exchanges (Zhang et al., 2019). Understanding the nature and quantity of the groundwater-pit water exchanges are also directly linked to the water quality with respect to the permeation of the soil-sequestered compounds and contaminants into the groundwater (e.g. Herzsprung et. al., 2010). Care should be taken to maintain that the water withdrawal rates balance the influx rates. Further land-use changes over pre-and post-mining scenarios can further influence the ecosystem properties and ecosystem services as evidenced from global examples, these are important considerations from a sustainability perspective (e.g. Larondelle and Hasse, 2012). Hence, a detailed model of the water exchanges is an important pre-requisite for the sustenance of pit lakes, beginning with the prediction of time for lake-stabilisation post the initial filling including the depth of equilibration. Hence, the most important consideration is to develop self-sustaining systems without co-dependency on water recharge networks or reversal of groundwater flow regimes leading to acidic reflux in the pit lake situated in the immediate vicinity (Werner et. al., 2001).

From the perspective of exchanges with adjacent aquatic systems, it is important to examine the relationships with the aquifer systems of the pit lake. From the design perspective, it is important to keep in mind the optimum 'water inrush coefficient' considering the effective thickness of the hydrogeological barrier (e.g. Wu and Zhou, 2008) to be incorporated into the pit lake design at the initial phases of construction. It is necessary to design the lowest seepage coefficients and leakance for pit lakes based on detailed local models of the water balance for the pit lake systems to be created (e.g. Genereux and Bandopadhyay, 2001). Such models can also provide critical estimates of critical lake depths for futuristic scenarios where maximum in-filling and highest lake levels are expected to be reached (e.g. Foley et. al., 2012; Unsal and and Yazicigil, 2015).

It is important to delineate the extent of the chemocline layers within the pit lakes and to model the rate of diffusion of the ions across the boundary layer from oxic to anoxic conditions (e.g. Boehrer et al., 2009; Luek et.al., 2017). Since it is found to vary widely, the design of the pit lakes of different depths must take in to account the approximate depth at which the chemocline is likely to occur (Figure 4). For example, for a pit lake of approximately 30 m depth, the chemocline can occur between 15-20 m, just a few metres above the hypolimnion and monimolimnion. During the design phase, the estimates of depth of the transition between oxic and anoxic environments must be available to determine the need and extent of aeration required to maintain a non-stagnant monimolimnion. For example, it has been observed that the water renewal times of the monimolimnion must be equal to or closer to the renewal times of the whole lake for the ecosystem to remain free from perennial stagnation (e.g., Campbell and Torgersen, 1980). Layering the mine voids with lime is suggested as a useful alternative. This is because the presence of alkaline products in the monimolimnion can help to assimilate the acidic products of ionic reduction, which is likely to be encountered in the lower parts of the pit lakes. Lime application can balance the pH of the monimolimnion as with mechanical interventions as the aeration of the chemocline, the recirculation of the ions can be maintained. Studies have shown that such measures as removal of excess phosphorus by co-precipitation with iron (Fe) and aluminium (Al) before the initial filling-in would be helpful to sequester the excess P in the sediments and avoiding eutrophied conditions (e.g. Herzsprung et. al., 2010). The risks of leaching of sulphide weathering products from the drained mining surface during periods of low lake levels can influence the buffering capacity of Fe and Al to a great extent (Werner et. al., 2001). At the same time, the stability of the monimolimnion is also dependent upon the redox cycling of Fe and manganese (Mn), which in turn increase the sequestration of phosphorus and toxic metals in the sediments (Campbell and Torgersen, 1980; Herzsprung et. al., 2010). These considerations on the chemical processes that drive the sustainability of pit lakes must also be incorporated within the design of pit lakes.

Recent reports have indicated that pit lakes systems of low pH (of the order of 3) are also capable of sustaining a species-rich consortium of planktonic and microbial biota depending upon the morphometry, wind-driven circulation and trophic statuses (e.g. Weithoff et.al., 2010).Species of cyanobacteria (Downey et al, 2001), *Daphnia sp.*(Friese et. al., 2003) and *Ochromona sp.*, *Lepocinclis sp.*, colonies of heterotrophic bacteria etc. are capable of colonising the pit lakes successfully. Aquatic macrophytes species such as *Potamogeton malainus*, *Ipomoea fistulosa*, *Typha angustifolia*, *Alternanthera philoxeroides*, *Vallisineria spiralis*, *Hydrilla verticillata*, *Marsilea minuta*, *Nymphoides indica* and *Nymphaea nouchali*were also reported to be able to colonise open-cast pit lakes successfully (Pal et.al. 2014).

2.3 ENVIRONMENTAL CLEARANCE GUIDELINES AND PRACTISE

Concerns about the follow-up programme to restore the environmental services of mined landscapes have been vociferous over the past few years in India and other parts of the world (Australian Mine closure report, September 2016).The MOEFCC Regulations 2018 (Annexure 15) of India has laid down the standard environmental compliance (EC) regulations for open-cast coal mines with emphasis on the strategies for water quality monitoring and preservation including the references to the surface and groundwater characteristics along with effluent quality. According to the EC guidelines, backfilling of the overburden up to 40 m before the conversion to pit lake system has been recommended. Further, the creation of the pit lake can be used for augmenting the groundwater resources over a long term. These guidelines are prescribed with a view towards creating self-sustainable systems from the pit lakes.

It is usual practice to pursue such follow-up activities through specific institutional and regulatory arrangements as per the EIA submitted at a pre-planning phase (Soni and Wolkersdorfer, 2016). These activities are determined by factors such as the type and scale of the project, resources available for implementation and monitoring, the project initiators and the maintenance of the restored landscapes through active policy frameworks (Thakur and Fischer, 2008). The perspectives of the coal mineowner as well as the cost-benefit analyses tend to drive the success of the end-of-life management of mine voids (Hamann, 2003). For example, from a policy perspective, it would be quite important to envisage pit lakes as environmental resources available for long-term usage after the ceasing of mining operations. This is a consideration that needs to be included at a pre-planning stage itself. However, such foresights require close attention to the financial viability of the pit lakes as sustainable water basins. Further scientific inputs in terms of the complexity of technological operations needed to create, manage these lakes have to be addressed at the planning stages itself. These inputs at the pre-planning stages are essential to discuss the sustainability and viability of the coal mining operations.

Table 1 below provides a compilation of the status of different pit lakes in India along with their environmental and management statuses. These data highlight the importance for a strong policy framework to manage such pit lake ecosystems with scope for eco-restorative measures. For example, the older pit lakes from Raniganj and Jharkhand have medium depth-to-surface-area ratios, which are likely to change in the recent times with greater resource extraction practices leading to deeper excavations, resulting in the deeper void spaces. This scenario needs a different management plan compared to the mine voids, which are in the initial stages of construction and development.

Table 1 : A list of pit lakes in India with their environmental characteristics, plans for end-usage as well as issues from a management perspective.

Pit lake system	State	Category of mine	Indication of end-use	Depth (m)	Surface area (km^2)	In-filling source	Issue highlighted	Reference
Manikpur Pilot Quarry	Chattisgrah	Open-cast, coal	Water reservoir for domestic purpose after treatment	48	0.19	Precipitation, groundwater influx	Depth management	Pratapan et. al., 2012
Several pit lakes in the Mangalpur industrial area, Raniganj	West Bengal	Open-cast, sub-bituminous coal	Dumping of industrial effluents	>20 m	Na	Precipitation and groundwater influx	Contamination of water due to industrial effluents	Gupta et.al.,2010
Several pit lakes in the Mangalpur industrial area near Raniganj	West Bengal	Open-cast, coal	Dumping of industrial effluents	na	0.064	Precipitation and groundwater influx	Anthropogenic pollution through influx of industrial discharges; effects of weathering on water quality	Gupta et.al.,2012

Several pit lakes in the Damodar Valley coalfield and in the East Bokaro Coalfield	Jharkhand	Open-cast, coal	Evaluated for irrigation	na	Na	Riverine influx from Bokaro, Konar and Damodar rivers	Change in surface water characteristics due to mixing of coal mine water with riverine water	Mahato et. al., 2017
Several pit lakes in the Raniganj-Asansol coalfield near Burdwan	West Bengal	Open-cast, coal	Evaluated for pisciculture	18.3	Na	Precipitation and groundwater influx	Stratification and changes in water quality of the abandoned pit	Mondal et. al., 2015
Raniganj coalfields pit lakes - Millenium, Kumardihi, Bankola area,Purusattampur East and West, Jhanjra area	West Bengal	Open-cast, coal	Assessed suitability for drinking, irrigation and aquaculture purposes	35-36	0.08-2.76	Precipitation and groundwater influx	No issue was indicated for the use of the water for drinking, irrigation and aquaculture	Pal et. al., 2013
Raniganj coalfields pit lakes - Millenium, Kumardihi, Bankola area,Purusattampur East and West, Jhanjra area	West Bengal	Open-cast, coal	Eco-restoration process studied using sediment characteristics and macrophyte diversity	35-36	0.08-2.76	Precipitation and groundwater influx	Low sediment quality	Pal et. al., 2014
29 limestone pit lakes located in Raipur and Baloda Bazar	Chhattisgarh	Limestone pits	Evaluated for drinking water and irrigation	3.0-21.0	0.013-0.1	Limestone leachate run-off, precipitation	Microbial and surfactant contamination	Ramteke et. al, 2016
Kerendari OC Project(yet to be opened)	Jharkhand	Open-cast, coal	Unorganised water reservoir envisagedfor use after 30 years for irrigational, industrial purposes or pisciculture	45	5.6	Rainwater accumulation and harvesting, through pumping from available nearby resources	Difficulties in manipulating the chemistry of pit lake and long time needed to achieve remediation goals	Soni et. al., 2014

Neogi et al (2018) have found that mine water samples collected from the sumps of opencast and underground coal mines in the North Karanpura coalfield of Jharkhand have high heavy metal concentrations, making the mine water unfit for human consumption. Therefore, it is critical for the mine owners to install appropriate water treatment systems designed and operated to provide water meeting the required standards either for irrigation and/or human/livestock consumption and clearly label the mine water as such.

From the policy angle, a distinction has to be made between older, abandoned mines without water or overburden infilling as against newer, naturally-refilled pit lakes. Management of their environmental qualities can be addressed by, considering appropriate design parameters for the specific ecosystems and/or treatment options for remediation. In the case of futuristic pit lakes, a strong policy framework to establish design criteria and management of ecosystem must be established at the initial stages itself for long-term monitoring and assessment.

3.0 CONCLUSIONS

From the perspective of the environment, the need for policy formulation regarding pit lakes must be focussed on the strategies to build sustainable ecosystems with a range of end-use scenarios evaluated as a part of the robust long-term management strategies rather than self-sustaining systems since some form of treatment may be required in most cases to ensure that the pit lake is of use to the local communities. It is important that care should be taken to protect against anthropogenic pollution of these manmade ecosystems through the implementation of policy-based framework for their maintenance in India (e.g. Soni and Wolkersdorfer, 2016). In another parts of the world, for example, the European Community Water Framework Directive (WFD; EC 2000; Nixdorf et al 2005) has placed great stress on the preservation of the "good ecological quality" of mining lakes through active managerial interventions. Such a framework is a significant need of the hour in the Indian context.

Declaration of pit lakes as new resource-bases and as 'ecological hotspots' may be effective means to channelize the management strategies to achieve active ecosystem services from pit lakes. Finally, the intended usage of the pit lakes must be considered for creation of the new resource-bases; possible uses would be to support fishes and avian biodiversity along these lakes, as a reservoir for water to supplement the industrial drawal needs, or as a restored recreational ecosystem. Each of these end-usage scenarios demand nurturing different types of management options, cost-to-benefit analyses and stakeholder involvement decisions. Such studies now need to be carried out in India in order to fulfil the mandate imposed *vide* Section 20A of the Mines and Minerals (Development and Regulation) Act which empowers the Government of India to issue directions to the State Governments in respect of restoration and reclamation activities to make optimal use of mined-out land for the benefit of the local communities.

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