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Implications of Coalfield Dynamics on Associated Ecosystems: A Tangential Review

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Authors' contributions

This work was carried out in collaboration among all authors. Author JNP planned and designed the review, managed partial literature search and wrote the first draft of the manuscript. Author PSG finalized the entire draft along with rectifications, managed partial literature search and performed all sort of correspondence. Author GRN managed partial literature search and corresponding implications. Authors PPP, SVP, SKS and PGG managed the respective literature searches. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Traditionally, the coal has stood as a resourceful entity for the energy demands of the society. The coalmines are the driving forces in the sufficing the energy and economy of the nation. Certainly, the existence of coal and its excavation is a much aspired endeavours for the development of any society. There are numerous prospective, functional and abandoned coalmines all over the world. Along with the intrinsic worth of the coal excavations, many studies have decisively elucidated the associated environmental complications. The ecological devastation is one of them. The ecological sphere whether it be macro or micro, is a fragile entity and must be taken care of accordingly. The process of coal excavations involves large scale landscape alteration where the entire native vegetation is removed. The ecological domain developed through an extensive period over the landscape vanishes in no time. The hydrological fluctuation also in terms of water chemistry destroys the aquatic habitat prominently known as hydroecology. The microclimatic shift is also a factor affecting drastically on the associated ecologies. The present review article strives to understand the various influencers in the coalfields dominating over the accompanying ecologies through selective endeavours executed all over the world. It also deliberates the probable measures to be taken to shield the associated ecologies in and around coalfields including the sensitization drives for protecting ecologies.

Keywords: Ecology; biodiversity; hydro-geochemistry; bioaccumulation; phytoremediation; coalfields.

1. INTRODUCTION

In the contemporary world the ecology is in constant threat from the mismanaged anthropogenic endeavours. These threats are influential on all scale, right form micro to macro. The sympathetic of the vulnerable and affected ecologies is expected by the working fraternity. As macro-scale retains wider perspective, the patterns prompted by the ecological courses should be perceived for the requisite management on the macro-scale (Fei et al., 2016). The deliberations over the macro-system ecology also termed as macro-ecology has become usual due to its competence in delineating the spatial patterns concerning biodiversity (Gaston and Blackburn, 1999). At macro-ecologies are typically influenced by the geo-physical processes (Heffernan et al., 2014). They are sturdily associated with the landscape ecology too. The landscape ecology competently pedals the spatial configurations and diversity of the ecological processes (Turner, 2005; Wu, 2013). Thus, the landscape alteration exhibits drastic and multifaceted consequences over the macro-ecology.

The exponential expansion of anthropogenic accomplishments has adversely affected the delicate balance of eco-environmental setups (Ali et al., 2019). The dynamic coalfields are the part of such accomplishments, which constitutes mine pits, dumps, tailings, etc. It is an established fact that the mining setups including coal mines manifested grave effects on the macro-ecology (Chaulya et al., 2011). The coal deposits are traditionally excavated by either removing the overburden rocks strata under which the coal is concealed establishing open cast mine or by tunnels establishing underground mines. The former type generates enormous waste and involves colossal landform transformation than latter. Such alteration in the landscape radically impacts the macro-ecology in terms of vital processes, flow of nutrients, biodiversity in general and the habitability of the organism in specific (Turner, 1989). Multiple endeavours evidently elucidated the deterioration of eco-environment in the proximity of the coalfields (Garai and Narayana, 2018; Goswami, 2015; Singh et al., 1997; Wang et al., 2019). The defensive management for existing ecology and the restoration of lost ecological systems have to be in a priority list of comprehensive initiatives (Tilman et al., 2014). The present article deals with a shallow evaluation over the selective endeavours done in concern to the ecological instabilities in and around coalfields. It is ultimately intended to execute a through

deliberation over the ecological issues for the targeted readers.

2. APPROACH

The requisite perspective regarding the ecological shifts in and around coalfield has been achieved by the comprehensive literature review. To be specific, the prime objectives are to evaluate the implications of various activities occurring in coalfield on the associated ecosystem and to elucidate the process of implications to institute the remedies. The portrayal of ecological issues in and around coalfields has been entirely based on the selective but proficient endeavours. The works specifically designed to interpret the implications of coal mining related activities on the adjacent eco-environment were considered as the points of reference for the review. A discrete evaluation for every referred work was done by associating the coalfield dynamics with the reports of eco-environmental issues. The convergence of evidence acted as a tool to infer the productive elucidations. The inclusive reportage of the article has been kept specific to the active coalfields where the landscape alteration, hydro-geochemical deterioration, deforestation, mismanaged afforestation, dropping heterogeneity in biome and etc. are prevailing.

3. COALFIELD DYNAMICS AND ECOLOGICAL UNCERTAINTIES

3.1 Landscape

The noticeable features constituting both natural and manmade across the particular land area is usually termed as landscape. A physical setup of the landscape includes landforms viz., hills, water bodies, soil cover, etc., ensuing into a biome fostering deeply influenced biodiversity (Forman, 2014; Turner et al., 2001; Wu and Hobbs, 2007). Hence, the study of the ecological processes and respective interaction implying the spatial biodiversity within a landscape stands crucial (Clark, 2010). The study is also referred as landscape ecology by renowned workers (Forman and Godron, 1986; Leser and Nagel, 2001; Troll, 1939; Wu and Loucks, 1995).

The geological setup holds a crucial position in the evolution of the any landscape. The geological formations incorporating distinctive mineral deposits also provide a flourishing ground for the unique biodiversity (Tibbett, 2015). The exploitation drive of such strategic minerals not only alters the concerning landscape but also destroys the sensitive landscape ecosystem thrived through a long haul. The coal is one of such deposits whose exploitation involves a major landscape alteration (Park et al., 2019). The coal deposits are conventionally hosted by the sedimentary rocks of selective geological formations, concealed under the overlying rock mass also termed as overburden. Traditionally the exploitation of these coal deposits has been done by excavating the overburden (Singh, 2005). Even today, the most of the coal mines are of open cast in nature due to fewer expenses (Mukherjee and Pahari, 2019). The foremost consequence of open cast mining is the destruction of spatial ecosystem due to profound quarries and gigantic dumps of excavated waste material. Multiple studies have evidently signified the major disruption of landscape and corresponding ecology by coal mining practices (Akiwumi and Butler, 2008; Mishra, 2005; Prakash, and Gupta, 1998).

3.2 Hydrology

The hydrology is a comprehensive study of water either existing at surface or subsurface level of earth. The study essentially includes the physical, chemical and biological processes and interactions water performs during its course. The hydrosphere as a whole is an indispensible part of a macro-ecosystem. A change of any sort in the hydrology could create a chaos in the vital interactions. In coalfields the hydrology distorts substantially due to the accretion of mine soil with different hydrologic properties than the native ones (Evans et al., 2015). The mega excavations in coalfields disrupt the usual hydrogeological flows paths triggering haphazard sub-surface flow (Bonta et al., 1992). Along with the physical setup of the surface and subsurface water in the active coalfields, the expected hydro-chemical pattern also shifts radically (Ganvir, 2019; Acharya and Kharel, 2020). Basically, to understand the impact of coal mining on the macro-ecology, following sub-domains must be assumed before evaluation.

3.2.1 Hydroecology

The recently bloomed opportunities in the hydrology also incorporate the elements of ecology along with study of water (Younger, 2002). The hydroecology or ecohydrology is a lately settled sub-domain of hydrology appraising the interaction between the hydrosphere and the ecosystem (Baird and Wilby, 1999; Nuttle, 2002).

The strength of said interaction is evident as water is the vital supporting element of life and both can be tooled to regulate one another (Zalewski et al., 1997). The interactions may include water usage by flora, acclimatisation of flora and fauna in concern to altered hydrologic environment, implications of vegetation on the surface and sub-surface water, etc. In the active coalfields the rapid fluctuations in the surface water bodies and groundwater flow paths are quite evident as a consequence the uncertainties for the ecohydrology stay inevitable.

3.2.2 Hydro-geochemistry

This sub-domain is categorized to study the groundwater chemistry with respect to the hosting geology. The chemical interactions and transactions within groundwater and between the minerals in the geological setup and groundwater are evidently elucidated by hydro-geochemistry (Singh et al., 2020). Such studies not only disclose the facets of rock-water interaction but also qualify the water for biotic usage (Sadashivaiah et al., 2008). The chemistry of the groundwater regulates the flux of nutrients and inorganic ions to the surface water bodies which are the microhabitats for many species (Hayashi and Rosenberry, 2002). The interaction of groundwater discharge and surface water bodies generates a crucial unit of lotic ecosystem termed as hyporheic zones (Brunke and Gonser, 1997). The riparian vegetation is habitually nurtured by the groundwater in turn augmenting the flux of organic matter into stream (Barton et al., 1985). The disorder developed in the subsurface water flows, descending water table, contamination from the leachates are some of the typical concerns in the active coalfields (Pulles et al., 1995; Sarkar et al., 2007; Younger et al., 2002). Around coalmines the groundwater, surficial aqueous bodies and soil systems are the most vulnerable to the toxins like of heavy metals, in turn triggering problems of bioaccumulations (Dubey, 2011; Gupta, et al., 2010; Jambhulkar and Juwarkar, 2009; Khan et al., 2015; Malik and Maurya, 2014; Maurya and Malik, 2019; Rai et al., 2011; Zainab et al., 2023).

3.3 Microclimate

The coalfields with active coal mines may hold a typical set of factors causing a microclimate. This set may include factors like temperature, humidity, precipitation, etc. The amputation of the native vegetation cover is the common procedure for the excavation process and dumping of the waste product creates colossal barren lands. Such intense deforestation and devegetation puts straight impact on local climatic factor including temperature. The temperature is the regulatory system for many organisms' behaviour, survival and reproduction (Clarke, 2017). The interaction of newly developed surface water bodies in the coal mines with the sun radiation enhances the evaporation process augmenting the humidity. The thriving of insects as a crucial process of an ecosystem stands vulnerable during the local variations in the temperature and humidity (Jaworski and Hilszczański, 2013). The climatic humidity has also proved to be a crucial factor for mediating species richness and community biomass (Li et al., 2020). The transformed topography in the coalfields provides a free passage to the wind. The dust particles developed during the mining activities also possess the calibre to alter the local precipitation rate by enhancing hydrometeors (Yin et al., 2002). All these factors discussed are reasonably sufficient to develop a microclimate in the coalfield. It is an established fact that the microclimate regulates the physiology of the organisms, ultimately influencing the ecosystem both at micro and macro-level (Zellweger et al., 2019).

4. HARMONISATION WITH ECOSYSTEM

The coal excavation is indeed a process of significance not only in terms of the energy requirements but also for the development of the nation. On the other hand, the fragile sphere of coalfield associated ecosystems is also on the verge of destruction at multiple locations. In an unceasing process of coal exploration and exploitation, a shield for ecosystems also turns out to be obligatory. Hence, the reinstatement of the disturbed equilibrium in the ecosystems surrounded by coalfields is the need of the hour.

4.1 Landscape Reclamation

The reclamation of the altered landscape in coal mines can be a problematic attempt as the site-specific issues are variable and no single measure can be engaged (Kuter, 2013). The landscape reclamation not only includes its fertility but the ecological facet too (Akpinar, 2005). The apposite identification of the land degradation characteristics is an essential for the concept of green mines (Hou et al., 2020). The remediation of the landscape is also a common term used for such endeavours. The usual approaches engaged in the landscape

remediation are rehabilitation, reclamation and restoration of which rehabilitation implies greater flexibility with stable ecological state, reclamation stands for before and after land usages are alike for original inhabitants and restoration is just a replication of original one offering less flexibility (Sahu and Dash, 2011). It is advisable that during or post coal excavation the landscape's remediation should be done in a manner to keep the native ecology as intact as it was before, hence the word of reclamation must have got higher significances. The vegetation, that too native are preferable options in the due course of landscape reclamation. The cases of planting the exotic tree species like *Prosopis juliflora* to stabilize the landscape has been reported at many coal mine sites but has also proved a hazardous for landscape ecology in due course of time (Arvind, 2007). The soil is the most affected entity in and around the coalfield and is usually contaminated by heavy metals leached out from mine spoils, acid mine drainage (AMD) resulting bioaccumulations in biota posing grave threats (Dubey, 2011; Rai et al., 2011; Talukdar et al., 2016). Thus, it is expected from the agency planning for landscape reclamation that to achieve sustainable solutions (Kumar, 2020; Kumar and Villuri, 2015). The phyto-remediation can be taken as an efficient tool in remediating the bioaccumulation issue (Pratap et al., 2020).

4.2 Sensitization to Hydroecology

As the hydrology in and around the coalfields is extremely affected, its corresponding consequences are obvious on the associated ecology. The natural aquatic habitats like lakes, ponds, rivers and stream around the coal mines are adversely affected specially in terms of water quality. Many studies have reported the heavy metal contaminations in such aquatic habitat resulting into bioaccumulation (Papadkar et al., 2023; Malik and Maurya, 2014; Youssef and Tayel, 2004). The vegetation established over the reclaimed soils possesses a deep influence over the surface and sub-surface hydrologic process (Clark and Zipper, 2016). Also the vegetation like *Typha, Phragmites, Eichhornia, Azolla, Lemna,* etc. is also considered to be efficient macrophytes in mitigating the heavy metal contamination (Rai, 2008). The artificial wetlands associated with the limestone drains have also been proved to be best options to regulate the hydro-geochemistry of the drainage otherwise causing the contamination in the aquatic habitats (Zipper and Skousen, 2014). The tactics designed for regulating water quality, hydrological aspects and aquatic habitations are must for the sound hydroecology (Cook et al., 2015). The overall approach has to be turned towards the sensitization towards the sustainability of the aquatic ecology prevailing around coalfields.

The similar kind of initiatives is needed in every sort of issue entangled with ecosystem occurring in and around coalfield. The agencies involved in the coal exploration sector should look after the linked ecosystems long before the initiation of the excavation process to minimize the forthcoming effects. The prospective endeavours must encircle the manifold spatiotemporal and integrative investigations converging towards biotic and abiotic interface, hydrological processes, natural and anthropogenic processes, linking geology with biological cycles and etc (Ganvir and Guhey, 2023; Kumar, 2024; Kumar and Gorai, 2018; Kumar and Prasad, 2023; Kumar et al., 2024; Li et al., 2017).

5. CONCLUSION

The coalfields are undoubtedly the prominent industrial sectors boosting the economy and satisfying the energy needs of the nation on one hand; whereas on the other hand the environment including the ecology associated with them is paying the price. Many studies evidently elucidated that the ecologies constituting both macro and micro are under a severe destruction in and around active and abandoned coalfields. The landscape is the first entity in the coalfield to be altered during the coal excavation, specifically in case of open cast coal mines. It is well established through many endeavours, that the alteration of the original landscape obliterates the entire ecosystem flourished on it. Similar is the case with the hydroecology, where the aquatic habitats are devastated and contaminated by the altered hydrological conditions in and around the active coalfields. The microclimate may not stand a major influencer but has been evidenced from many studies to be potential enough for affecting the associated ecology in the coalfields. There are certain established measures to overcome the imbalance caused by the coal excavations like of landscape reclamation, drainage treatment systems etc. But the attainment of the original which has been devastated at least in case of delicate ecology is a challenging task and takes substantial stretch. Ultimately, the sensitization of the agencies and stakeholders of all sorts

pursuing for the coal resource may prove to be a principal hit in ecological protections.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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