



Economic growth vs environmental and health costs: A study on Indian open-cast coal mines

Dr Debasree Dhar

Assistant Professor, Department of History School of Humanities and Social Sciences, Shri Guru Ram Rai University
Dehradun, Uttarakhand, India

Abstract

Open-cast coal mining, a dominant coal production method in India, is a critical energy source that significantly contributes to the nation's economic growth. However, this sector is intrinsically linked with substantial environmental degradation and adverse health outcomes for local populations and mining labourers. This study elaborates on the impacts of open-pit coal mining on India's environment and human health since 1975. It critically analyzes the multifaceted pollution of soil, water, and air from mining operations, elucidating the specific contaminants and their observed concentrations. Furthermore, the paper details the health conditions reported by communities residing near mining zones and the occupational health challenges faced by workers. The analysis illustrates existing policy frameworks, healthcare provisions, and the persistent challenges in mitigating these widespread negative externalities. The paper also highlights the pressing need for stronger environmental regulation, efficient abatement methods, and improved healthcare facilities to guarantee sustainable mining operations and safeguard public health in India.

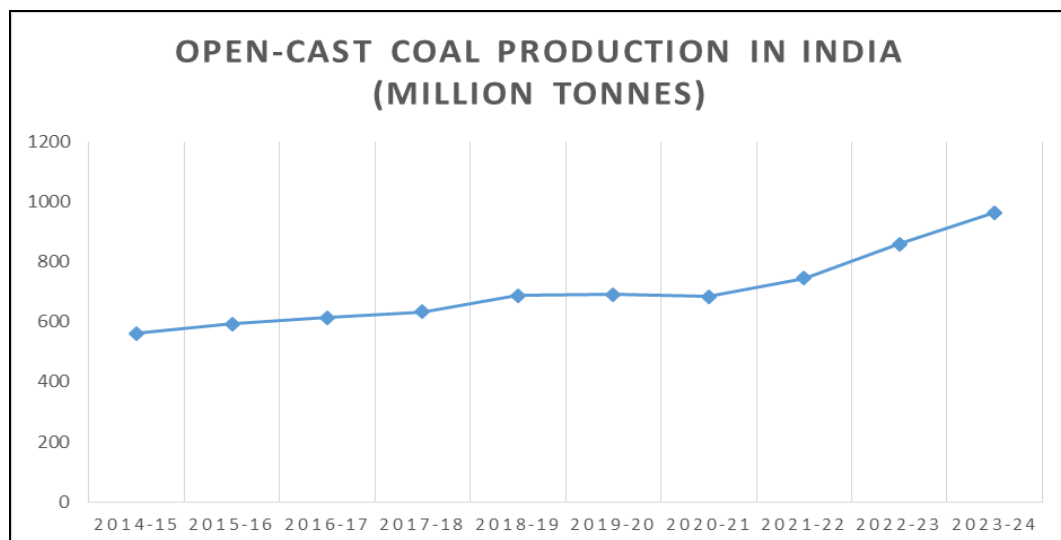
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Introduction

India, a country rich in fuel resources, depends extensively on coal as an energy source, especially in factories like iron and steel, cement, and brick (Jahan and Khurshid, 2020) ^[21]. The production of coal notably contributes to India's economic growth (Jahan and Khurshid, 2020) ^[21]. By 2011, India had produced 539.94 million tonnes (MT) of coal, securing the third position globally (Saha, 2024) ^[23]. Over the decades, India has significantly shifted towards open-cast mining (OCM) due to its ease of extraction (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) ^[7, 5, 8]. By 1996, open-cast mining accounted for approximately 70% of India's total coal production, a share that was projected to increase further (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) ^[7, 5, 8]. In 2023-24, the production of OCM was 962.52 MT, which was increased by 12.14% in comparison with the previous year

(see chart I). While providing substantial economic benefits, this extensive mining activity, particularly open-cast operations, has inevitably led to severe environmental degradation and a range of health problems, which are often overlooked as negative externalities (Jahan and Khurshid, 2020) ^[21]. These environmental and health hazards, including air, water, and soil pollution, pose significant concerns for India and the world today, impacting human development and well-being (Jahan and Khurshid, 2020) ^[21]. This paper illustrates the environmental and health consequences of open-cast coal mining in India from 1975 to the present. It illustrates the causes and consequences of pollution of the environment, including soil, water, and air. It assesses the health situation of the local populace and mining workers, discusses the ongoing difficulties, and examines the state's welfare programs and medical facilities concerning these problems.

Chart: I



Source: Production Opencast and Underground mines during the last ten years, Ministry of Coal, Delhi

Literature Review: Context, Relevance, and Critical Analysis

Existing literature broadly acknowledges that mining and mineral processing, including coal mining, lead to considerable environmental degradation and associated health issues (Jahan and Khurshid, 2020) [21]. Research indicates that, compared to underground mining, opencast coal mining has a more extensive negative impact on air quality due to the release of dust and gaseous pollutants in and around mining areas (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) [7, 5, 8]. This is primarily due to the large-scale removal of overburden and the resulting emission of fine particulate matter by excavators, transport vehicles, loaders, and conveyor systems (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) [7, 5, 8]. The practice also results in large cavities in the landscape (Zobrist and Giger, 2013) [33]. Nevertheless, accurately assessing the environmental health impacts is often difficult because of the numerous contributing factors and the absence of standardized evaluation methods (Dudka and Adriano, 1997) [4]. Some studies highlight that a lack of standardized assessment methods hampers effective mitigation and policy-making and recommend the adoption of uniform environmental monitoring protocols (Ugupta and Singh, 2017; Jahan and Khurshid, 2020) [32, 21]. Therefore, in the absence of strong legal enforcement, miners continue to face high rates of respiratory, musculoskeletal, waterborne, and skin diseases (Sahanaa and Murugan, 2023; Khurshid, 2022; Singh et.al., 2013) [24] [13] [28]. Studies pointed out that comprehensive risk assessment and mitigation strategies are essential to protect miners' health, and that policy reforms are needed to address emerging hazards in modern mining operations (Srivastava and Raichur, 2015) [29]. Methodological inconsistencies, such as the automatic assumption of normal distribution for elemental concentrations in soil contamination studies, when geometric means might be more appropriate for skewed data, also raise concerns about the accuracy of reported findings (Dudka and Adriano, 1997; Upadhyay and Mishra, 2015) [4, 31].

Some case study documents the negative effects of coal mining on local vegetation, including reduced species diversity and impaired plant growth. It argues that mining-induced land degradation threatens ecological stability and advocates for systematic reclamation and reforestation efforts (Pandey and Singh, 2010; Kumar and Pandey, 2013; Singh and Ugupta, 2017) [19, 14, 27]. A recurring theme in the literature is the inherent trade-off between economic development and environmental protection. While environmental aspects are increasingly integrated into mineral production, this often prolongs the development time and increases production costs (Dudka and Adriano, 1997) [4]. In many developing countries, where the extractive industries constitute a critical source of revenue and foreign exchange, there is often reluctance to impose what are perceived as "non-essential restrictions" on these key economic sectors. This hesitancy can impede the implementation of more stringent environmental regulations, as governments may prioritize economic gains over environmental protection, especially when law enforcement and regulatory capacity are limited (Bell and Donnelly, 2006) [1]. Despite mining causing substantial damage, it is important to note that the mining industry generally accounts for a relatively small portion of a

country's total land area (e.g., less than 1% in South Africa) (Bell and Donnelly, 2006) [1]. Moreover, although land degraded by previous mining operations can frequently be restored, such rehabilitation typically entails considerable financial investment (Bell and Donnelly, 2006) [1]. The transition from belowground to open-cast mining techniques in India has altered the nature of environmental impacts rather than eliminating them. Whereas underground mining primarily poses health risks to subterranean workers, open-cast mining results in more widespread degradation of air quality, affecting a broader population and the surrounding environment (Saha *et al.*, 2024) [21]. Given the intrinsic environmental and occupational risks, it is widely acknowledged that systematic and ongoing monitoring of both environmental conditions and workers' health is essential (Saha *et al.*, 2024) [23]. Studies like the one in Jharkhand emphasize the need to highlight major causes of illness in mining areas to draw attention from policymakers (Jahan and Khurshid, 2020) [21]. The literature points to identifiable sources of pollution directly linked to mining operations, including coal combustion, dumping, and transportation (Goswami, 2014) [9]. Specific mining activities like excavation, crushing, and loading are known to generate dust (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) [7, 5, 8]. The long-term nature of certain environmental impacts, such as Acid Mine Drainage (AMD), which can continue even after mining ceases, necessitates ongoing investigation and remediation efforts (Zobrist and Giger, 2013) [33]. Despite the existence of various policies and regulatory institutions, environmental degradation continues to pose a significant threat in many mining communities. Factors such as low entry barriers to mining, inadequate research methodologies, poor coordination among regulatory authorities, and insufficient resources have all contributed to the persistence of environmental devastation (Dubey, 2017; Bhattacharya, 2021; Pramod, 2025) [3, 2, 20]. Studies highlight that unregulated and irresponsible mining activities have resulted in severe ecological damage, including deforestation, soil erosion, loss of biodiversity, and water contamination, with regulatory enforcement and inter-agency collaboration often proving ineffective in mitigating these impacts (Dubey, 2017; Bhattacharya, 2021; Pramod, 2025) [3] [2] [20]. As a result, the intended benefits of mining sector reforms are frequently undermined, leaving local ecosystems and communities vulnerable to ongoing harm (Dubey, 2017; Bhattacharya, 2021; Pramod, 2025) [3] [2] [20]. Assessing the environmental and health repercussions of open-cast coal mining in India is of critical significance, considering the sector's essential contribution to the nation's energy security and economic framework (Nayak and Roy Chowdhury, 2018; Mishra and Das, 2017) [17] [16]. As coal remains a fundamental energy resource globally, the demand for it intensifies in parallel with ongoing industrial development and expansion (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) [7, 5, 8]. However, coal utilization—especially through open-cast mining—has been closely linked to substantial environmental degradation, most notably the decline in air quality resulting from increased concentrations of suspended particulate matter (SPM), sulfur dioxide (SO₂), and nitrogen oxides (NO_x) released during mining operations and associated activities (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007; Singh, 2019) [7, 5, 8, 26]. The livelihoods and health of

people who rely on these shared resources are in danger because of widespread soil degradation, water pollution, and the loss of native flora brought on by open-pit mining. These issues have also seriously interrupted agricultural operations and decreased access to clean water (Goswami, 2014; Sirur, 2024) ^[9, 25]. The coal industry has produced significant economic gains, but its negative effects on the environment and human health have become urgent national issues. Coal is still essential to India's economic growth and energy security because it generates a large portion of electricity and is used in industry, but its negative effects—such as air and water pollution, land degradation, and elevated health risks for mining communities—have drawn more attention and calls for more environmentally friendly methods (Jahan and Khurshid, 2020) ^[21]. Health issues, considered negative externalities, have historically received less attention, making research in this area crucial for policy intervention (Jahan and Khurshid, 2020) ^[21].

Effects on the Indian Environmental landscape

Open-cast mining activities in India place intense strain on the environment, resulting in substantial pollution of air, water, and soil. These combined effects contribute to the deterioration of natural ecosystems and negatively affect human health and quality of life.

1. Air Pollution

Air pollution is repeatedly recognized as a key indicator of the environmental impact associated with mining activities (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) ^[7, 5, 8]. Dust emissions, particularly suspended particulate matter (SPM) and respirable dust, represent the primary air pollution challenge associated with open-cast mining operations (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007; Pandey, Tripathi and Mishra, 2008) ^[7, 5, 8, 18]. Open-cast mining involves a massive overburden removal using excavators, transporters, loaders, and conveyor belts, all of which result in a “massive discharge of fine particulates” (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) ^[7, 5] ^[8]. Drilling and cutting operations also contribute significantly to dust generation (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) ^[7, 5, 8]. Additionally, coal combustion, dumping, and transportation processes associated with coal mining contribute heavily to air pollution (Jahan and Khurshid, 2020) ^[21]. Coal dust is spread along the whole transit path when coal is transported in open wagons or uncovered, leaky trucks from the pithead to loading or consumption locations. Road travel is the main source of air pollutants in most coalfields; in the Jharia coalfield, vehicle movement is responsible for about 47% of all suspended particulate matter (SPM) (Goswami, 2014) ^[9]. Additionally, the persistent issue of spontaneous coal combustion, both underground and in open-cast mines, remains a significant challenge, particularly in the Jharia Coalfield. Historically, this region has been plagued by extensive coal fires, with recent efforts reducing the number of active fire sites from over 70 to 27, and the affected area shrinking from 17.5 square kilometers to about 1.8 square kilometers (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12]. These fires emit “huge amounts of noxious gases, including poisonous CO”, in addition to SO₂, CO₂, and higher hydrocarbons (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12]. Fires in open-cast mines often produce thick clouds of gas and smoke, resulting in

reduced visibility and dangerous working environments. Additionally, blasting activities in both underground and surface mines generate significant vibrations and noise pollution (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12].

2. Water Pollution

The open-cast coal mining has a significant influence on groundwater systems as well as surface water bodies. It is needless to say that around the world, coal and metal mining regions are plagued by this problem. Acid Mine Drainage (AMD) is a significant issue that arises from the exposure of sulfide-containing minerals, including pyrite, pyrrhotite, and chalcopyrite, to air and water during mining operations. The sulfuric acid that is produced as a result speeds up the breakdown of other minerals, causing heavy metals, arsenic, and other hazardous substances to leak into the nearby leachate. AMD can originate from multiple sources, including underground and open-cast mine workings, spoil heaps, tailings ponds, and mineral stockpiles (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12]. Sources of water contamination in mining areas include suspended solids, dissolved salts such as chlorides and sulfates, acidity, and iron compounds. Additionally, mine water from open-cast operations may be contaminated with oils and flotation chemicals used in coal processing plants (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12]. Waste rock from open-cast mines can generate large volumes of AMD. Tailings, fine-grained residues from crushing ore, are often disposed of as slurries in tailings dams and can contain processing chemicals like cyanide (from gold mining) and heavy metals from various ores. These can cause significant pollution of ground and surface water through seepage (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12]. The extraction of coal disturbs aquifers and lowers the water table, leading to mineral leaching that affects water quality (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12].

Mine effluents frequently contain high levels of dissolved chlorides, nitrates, phosphates, and sulfates of elements such as sodium, calcium, magnesium, and iron, leading to the formation of hard water that is unfit for industrial applications as well as for human consumption. High electrical conductivity values further indicate significant mineralization. In the Jharia coalfield, average wastewater characteristics reveal high levels of total hardness, chlorides, and sulfates (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12]. Acid mine drainage significantly increases heavy metals and sulfate concentrations in affected water bodies. Research from the Witbank Coalfield has reported sulfate levels commonly ranging from 2,000 to 3,000 mg/l. Heavy metals such as aluminium, manganese, copper, zinc, and lead are frequently found in contaminated waters. For instance, water samples from the Blesbokspruit, an area impacted by coal mining, showed aluminium concentrations between 80 and 240 mg/l, in stark contrast to 0.59–0.8 mg/l in unaffected streams. Such contamination can devastate aquatic ecosystems and surrounding vegetation (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12]. Spills of lubricating and hydraulic oils underground can pollute mine water with organic compounds (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12]. Turbidity and sedimentation from suspended solids have a detrimental impact on aquatic ecosystems. Rivers such as the Ankobra and Asesree in Ghana—mirroring conditions found in India—have been severely polluted by mining activities, making them unsafe for domestic use. Such contamination can result in the loss of

aquatic species and the depletion of vital water resources for drinking and livelihoods in local communities. Arsenic pollution has also been detected in drinking water sources—including streams, shallow wells, and boreholes—near mining areas, primarily due to mine-related pollution and the natural oxidation of sulfide minerals. Following mine closure and the cessation of dewatering, groundwater levels tend to rise. If this water resurfaces, it can carry highly acidic and iron-rich effluents laden with heavy metals, further contaminating surface water bodies and productive aquifers (Goswami, 2014; Ministry of Coal, 2025) ^[9, 12].

3. Soil Pollution and Land Degradation

Mining operations require the extraction of enormous quantities of rock and overburden, which are subsequently deposited as massive dumps in the surrounding areas. This process dramatically alters the landscape, converting extensive tracts of forest, agricultural, and pasture land into barren wastelands or mining settlements. Additionally, open-pit mines leave behind large cavities, further scarring the natural scenery (Zobrist and Giger, 2013) ^[33]. Surface mining entails stripping away the topsoil with heavy machinery to access underlying minerals, which diminishes soil fertility and productivity by exposing subsoil that is typically unfit for agriculture. Furthermore, overburden dumps—sometimes rising over 60 meters and spanning hundreds of hectares, not only mar the landscape but also produce dust and fine particles that can be carried into nearby water bodies, exacerbating environmental degradation (Zobrist and Giger, 2013) ^[33]. Additionally, fine-grained residues from ore processing, usually managed as slurries, are stored in tailings dams. These tailings often have low organic matter and minimal plant nutrients, and their toxicity to vegetation is heightened by the presence of sulfide minerals capable of generating acid mine drainage (AMD). As a result, tailings deposits pose a significant risk of contaminating both ground and surface water, as well as soil (Zobrist and Giger, 2013) ^[33].

Soils in areas adjacent to mining and smelting activities are adversely affected by the disposal of mine tailings, contamination from acid mine drainage (AMD), and the deposition of airborne pollutants released by smelters (Dudka and Adriano, 1997) ^[4]. Acidifying substances released from smelters, along with acidic runoff from mines and tailings, lead to significant soil acidification. This effect is intensified when sulfide-rich minerals are exposed to air. As a result, soil fertility declines, soil biodiversity diminishes, and the energy balance of soil organisms is disrupted. In acidic soils, metals become more mobile and readily absorbed by plants, increasing the risk of leaching and runoff into surrounding environments (Dudka and Adriano, 1997) ^[4]. Several substances are commonly contaminated during the processing of metal ores, with trace metals including zinc (Zn), lead (Pb), and cadmium (Cd) presenting serious threats to soil condition. Lead contamination in garden soils, often a legacy of historic mining activities, is a notable example. Additionally, flooding can transport heavy metals from abandoned mines onto agricultural land, sometimes raising lead concentrations to levels ten times higher than established safety limits (Zobrist and Giger, 2013) ^[33].

Open-cast mining often leads to the formation of large gullies, increased surface runoff, severe soil erosion, and diminished soil infiltration resulting from the loss of vegetation cover. The prevalent technique of mounding

topsoil harms the biological, chemical, and physical characteristics of the soil, decreasing its fertility and eliminating helpful microbes. Unfilled, abandoned mining pits make the terrain unsuitable and sometimes retain water, which provides breeding grounds for mosquitoes that spread malaria and constitute a major threat to both human and animal health. Although subsidence is more typically linked to underground mining, it can also occur in shallow workings, causing damage to surface structures, disrupting drainage systems, and transforming farmland into wasteland (Goswami, 2014) ^[9].

Health Condition of Local People and Labourers

Residents living in coal mining regions, particularly in areas like Hazaribagh and Dhanbad, frequently experience a range of environmental and health issues compared to those in non-mining areas. These problems stem directly from exposure to hazardous pollutants. People in these coal mining zones are especially vulnerable to various airborne diseases, including asthma, bronchitis, and other respiratory disorders, often worsened by the presence of sulfur gases. Common symptoms reported include cough, cold, allergies, and infections of the nose and throat. Moreover, fine particulate matter produced by mining activities can damage lung tissue, leading to conditions such as pneumoconiosis—a disease caused by the accumulation of microscopic dust particles in the lungs (Jahan, and Khurshid, 2020) ^[21]. Contaminated water sources lead to illnesses such as jaundice, typhoid, diarrhea, and cholera. The heavy pollution of rivers by mining activities, especially illegal small-scale mining, renders water unsafe for domestic use, causing significant depletion of drinking water sources. Arsenic contamination in drinking water sources has also been reported in mining areas (Jahan, and Khurshid, 2020) ^[21]. Additionally, elevated levels of trace elements such as iron, lead, zinc, copper, and cadmium in the ambient air of coal mining regions pose direct health risks through inhalation and bodily absorption. Lead exposure is especially concerning for children, as studies have found increased blood lead (Pb-B) levels among those living near mining areas. There is also a documented correlation between higher blood lead concentrations and reduced intelligence quotient (IQ) in exposed children, highlighting the severe impact of environmental contamination on community health (Dudka and Adriano, 1997) ^[4]. Skin diseases are also commonly reported by villagers in mining areas. The continuous production of radon gas from uranium tailings, even with a short half-life, poses a long-term hazard as it decays into solid radioactive products (like 210Pb) that, upon inhalation, can lead to cell damage and cancer. Unfilled, abandoned mining pits often accumulate water, turning into breeding grounds for malaria-carrying mosquitoes and posing serious health risks to both humans and animals. Residents of heavily polluted industrial areas—similar to those near mining sites—exhibit higher rates of cancer and circulatory disorders. Additionally, there is a direct link between airborne pollutants from mining activities and increased incidence of heart problems in these communities.

1. Health Conditions of Labourers

Coal mine workers, particularly those employed in open-cast mining operations, are exposed to a range of direct occupational hazards that can result in distinct health problems. These risks include prolonged exposure to dust,

noise, and hazardous chemicals, which can lead to respiratory diseases (such as pneumoconiosis and chronic bronchitis), hearing loss, skin disorders, and increased risk of injuries and accidents. The demanding and often hazardous working conditions in open-cast mines make occupational health and safety a critical concern for coal miners.

Respiratory Diseases

Black lung disease, or coal workers' pneumoconiosis (CWP), is directly caused by inhaling coal dust particles during work. This chronic industrial lung disease sometimes worsens long after exposure to coal dust has ceased. It occurs over many years of exposure. Sputum production, shortness of breath, and a persistent cough are signs of CWP, which causes inflammation and fibrosis of the lung tissue. The illness may eventually lead to early mortality and cause severe disability and impairment of lung function (Saha, 2024) ^[23].

The risk of acquiring asthma and Chronic Obstructive Pulmonary Diseases (COPD), such as emphysema and chronic bronchitis, is considerably increased by mining operations. Exposure to coal dust in mining environments stimulates inflammatory responses in the lungs, leading to tissue injury and the onset of these respiratory conditions. Studies have consistently shown that coal miners face higher rates of COPD and other chronic lower respiratory diseases compared to the general population, with the risk increasing alongside cumulative dust exposure. The inhaled coal dust particles trigger immune reactions that cause inflammation and scarring in lung tissue, contributing directly to the development and progression of these diseases (Saha, 2024; Laney and Weissman, 2014) ^[23, 15]. Silicosis, a condition characterized by breathing difficulties, reduced chest expansion, and heightened susceptibility to tuberculosis, results from inhaling silica dust, a major component of respirable dust produced during mining operations. In an open-cast mine study in Eastern India, average respirable dust levels in the mining section were found to be 3.8 ± 1.1 mg/m³, exceeding those measured in the crusher and loading areas. The study further indicated that 17.6% of workers had Forced Expiratory Volume in 1 second (FEV₁) values between 70% and 80%, suggesting some level of impaired lung function (Saha, 2024; Laney and Weissman, 2014) ^[23] ^[15]. Additionally, about 7% of workers displayed restrictive lung abnormalities, with a similar percentage showing obstructive patterns. Mean Forced Vital Capacity (FVC) was significantly lower among workers aged 45 and above, as well as among smokers, underscoring greater respiratory risks in these populations (Saha, 2024; Laney and Weissman, 2014) ^[23] ^[15]. Musculoskeletal pain is among the most frequently reported symptoms by workers in open-cast mines, with a prevalence of 16.8% observed in one study, significantly higher than the national average for the general population. This elevated rate is likely due to the intense physical demands and repetitive strain associated with mining work (Saha, 2024; Laney and Weissman, 2014) ^[23] ^[15].

Workers additionally experienced symptoms like chronic cough, shortness of breath, chest discomfort, and irritation of the mouth and throat. Some also reported headaches, trouble sleeping, overall fatigue, and finger tremors. These complaints underscore the broad spectrum of physical health

issues linked to occupational exposure in mining settings (Saha, 2024; Laney and Weissman, 2014) ^[23, 15]. A study suggested that approximately 6.4% of miners were found to be hypertensive, similar to findings in other miner populations (Saha, 2024; Laney and Weissman, 2014) ^[23, 15]. Apart from that, controlling noise in mining environments is difficult, and noise-induced hearing loss remains common. Explosions, heavy machinery, and transport systems contribute to noise pollution (Saha, 2024; Laney and Weissman, 2014) ^[23, 15].

Challenges in Addressing Environmental and Health Effects

Addressing the environmental and health impacts of open-cast coal mining in India is highly challenging due to the complex interplay of economic, social, and technical factors (Singh, 2019) ^[26]. The sector's operations generate significant air and water pollution, soil degradation, and adverse health outcomes for local communities, while also causing displacement and social disruption (Singh, 2019; Rinchin *et al.*, 2017) ^[26, 22]. These challenges are compounded by the need to balance the country's economic reliance on coal with the pressing necessity to mitigate environmental harm and protect public health, making comprehensive and effective solutions difficult to implement (Singh, 2019; Rinchin *et al.*, 2017) ^[26, 22]. One major obstacle is the difficulty in quantitatively assessing environmental health effects, as these are influenced by a complex web of interacting variables and a lack of standardized evaluation methodologies. Research in this field often suffers from insufficient quality control and inadequate statistical analysis, leading to inconsistent results and making meaningful comparisons difficult. Additionally, the economic and health burdens associated with occupational exposures are frequently underestimated, in part because many related diseases have multiple possible causes and long latency periods, complicating efforts to establish direct links to mining activities. As a result, health issues—often treated as negative externalities—have historically received limited attention in policy and practice (Jahan and Khurshid, 2020) ^[21]. Despite the presence of policies and regulatory institutions, environmental degradation continues to affect many mining communities. This persistence is often attributed to shortcomings in mining environmental policies and their enforcement. Key issues include the absence of best practice management systems for Corporate Social Responsibility (CSR), weak institutional frameworks, and a lack of transparency in legal and regulatory processes related to compensation and royalties. Additionally, communities are frequently excluded from the valuation and decision-making processes. The situation is further worsened by inadequate staffing and resources, poor mercury management practices, and insufficient coordination among regulatory agencies, all of which contribute to ongoing environmental harm.

Socio-Economic Barriers

In developing countries, the immediate economic benefits derived from mining frequently take precedence over environmental and social concerns, resulting in a reluctance to enforce strict regulations that might raise production costs. Communities most affected by mining—especially marginalized tribal populations, often face displacement and limited access to alternative livelihoods, pushing many

toward informal or illegal mining activities. The absence of genuine community involvement in environmental decision-making, along with inadequate environmental education and awareness, intensifies these ongoing challenges. Managing dust emissions is especially problematic, particularly from dispersed sources such as road transport. Achieving effective air pollution control necessitates a mix of preventive and suppressive strategies, as well as the implementation of dust extraction systems. Acid mine drainage (AMD) presents a long-term environmental liability, as its formation continues even after mining operations have ceased. Land reclamation is both costly and complex. Restoring soil fertility demands stable surfaces, non-toxic conditions, and adequate nutrients, often necessitating specialized remediation techniques such as clay capping or submergence. Predicting and managing ground movements, particularly from abandoned mines, remains a significant challenge. Unfilled pits not only render land unusable but also serve as breeding grounds for disease vectors like malaria-carrying mosquitoes. Additionally, extinguishing mine fires- such as those in Jharia- proves to be a complicated and expensive task, often yielding limited success. These fires can lead to the ongoing emission of toxic gases, including carbon monoxide, sulfur dioxide, mercury, and various organic and inorganic chemicals, and cause further land degradation, thereby intensifying the environmental and health hazards faced by mining communities. The persistent release of pollutants from coal fires not only contaminates air, water, and soil but also contributes to respiratory illnesses, land subsidence, and the destruction of habitats, compounding the risks for those living near affected sites (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007; Stracher, 2004) [7, 5, 8, 30].

State Welfare Policies and Healthcare Facilities

The far-reaching impacts of open-cast coal mining demand a comprehensive policy and healthcare response. While current sources underscore the gravity of these issues and reference some existing frameworks, they also expose significant gaps and ongoing challenges within India. The health hazards linked to coal mining are widely acknowledged as a significant issue at both national and international levels, with pollution from mining operations severely diminishing the quality of life for many affected communities. This situation underscores an urgent need for policymakers to prioritize and effectively address these challenges. While workers in the organized mining sector generally have access to health services and medical care- evidenced by initiatives such as health education programs for open-cast mine workers in Eastern India that raise awareness about chronic diseases and related risk factors, there remains a pressing need for more comprehensive and inclusive policy interventions to safeguard the health and well-being of all individuals impacted by coal mining activities (Saha, 2024) [23]. It is recommended that “regular and periodic monitoring of environmental conditions and the health status of workers” be implemented in mining operations. This approach acknowledges the significant environmental and occupational hazards inherent to mining and is essential for early detection of risks, timely intervention, and the ongoing protection of worker health and safety (Saha, 2024) [23]. In some areas, due to severe surface water pollution, the government has undertaken initiatives like digging boreholes to provide communities with access to groundwater for domestic use.

Environmental Policy Frameworks and Gaps

Internationally, conducting an Environmental Impact Assessment (EIA) is regarded as a prerequisite before initiating any new mining project. Additionally, an Environmental Management Program (EMP) is required to detail operational procedures and land reclamation strategies. These practices represent globally recognized standards that India should ideally adopt and rigorously implement to ensure responsible mining development and effective environmental stewardship (Bell and Donnelly, 2006) [1]. In developed countries, reclamation of mine sites after operations cease is legally mandated. While India has large areas of land degraded by mining, there is an observation that “no concerted and coherent effort has, however, been taken in this direction” for reclaiming subsided land through joint efforts from coal companies and local administrations. This indicates a gap between global best practices and local implementation (Goswami, 2014) [9]. There are currently no best practice management systems or nationally recognized standards for Corporate Social Responsibility (CSR) in place, making it difficult for companies to benchmark their efforts. Despite existing frameworks, environmental degradation continues, largely due to weak institutions and insufficient enforcement. The legal and regulatory systems also face challenges, particularly in the valuation and payment of compensation and royalties, as well as the exclusion of local communities from the valuation of their crops. Furthermore, there are notable shortcomings in environmental management systems and a lack of specific operational standards, such as those for blasting in host communities. These gaps hinder effective environmental and social governance in mining regions.

Recommendations for Policy and Healthcare Improvement (as suggested in sources):

Advancing sustainability in the mining sector necessitates that governments rectify deficiencies in environmental policy and substantially reinforce enforcement mechanisms. Meaningful community engagement in environmental governance is crucial- not only to advance sustainable mining has operations and safeguard projected outcomes, but also to strengthen democratic processes and mitigate conflicts between mining enterprises and local populations. Streamlining the registration procedures for small-scale mines may facilitate their incorporation into formal regulatory systems, thereby improving adherence to environmental standards. The formation of environmental monitoring groups within mining communities, coupled with the implementation of targeted environmental education and awareness programs, is advocated to promote more responsible environmental conduct. Furthermore, expanding the application of dust control agents on haul roads is imperative. Robust dust mitigation can be accomplished through the consistent use of water or detergents, alongside the installation of dust arresters during drilling. Collectively, these interventions are integral to reducing the environmental and health repercussions associated with mining activities (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) [7, 5, 8]. Utilizing waste materials like pulverized fuel ash from thermal power stations for backfilling mines can contribute to abating mine fires. Sealing surface fissures and crown holes that allow air

entry to mines is also crucial (Bell and Donnelly, 2006) ^[1]. A range of both active and passive treatment technologies exists for the management of acid mine drainage (AMD), each designed to neutralize acidity and remove dissolved metals. Active treatment methods, such as the application of lime and the use of clarifiers, rely on the direct addition of chemicals to remediate contaminated water. In contrast, passive systems- including anoxic limestone drains, constructed wetlands, and rock filters- harness natural processes to lower acidity and extract metals from mine effluent. Collectively, these approaches are vital for alleviating the environmental consequences associated with AMD (Bell and Donnelly, 2006) ^[1]. A cost-benefit strategy should be employed to quantify damage costs and control costs to adopt options that minimize both (Ghose and Majee, 2001; Ghose, 1989; Ghose and Majee, 2007) ^{[7] [5] [8]}. Mine closure plans, including provisions for reclamation and financial resources, should ideally be devised and implemented before mining begins to minimize future liabilities and risks. The reclamation of abandoned mines, such as by filling voids with materials like sand or pulverized fuel ash, is a viable solution to prevent future collapse and enhance land stability (Bell and Donnelly, 2006) ^[1].

Conclusion

Open-cast coal mining, while integral to India's energy infrastructure since 1975, has engendered profound and multifaceted environmental and public health crises. Chronic air pollution- driven by elevated concentrations of suspended particulates and toxic gases from extraction, transportation, and persistent mine fires- has severely compromised ambient air quality. Water resources face significant threats from acid mine drainage and heavy metal pollution, which compromise the quality of both surface and groundwater and reduce the availability of safe drinking water. Soil systems have suffered extensive degradation through land transformation, topsoil loss, acidification, and the accumulation of toxic tailings, resulting in widespread infertility and heightened erosion risk. These environmental degradations translate directly into acute and chronic health burdens for local communities, manifesting as respiratory, dermatological, and waterborne diseases, trace metal toxicity, and vector-borne illnesses from stagnant waters in abandoned pits. Mine workers, particularly in open-cast operations, face heightened occupational risks, including musculoskeletal disorders and a disproportionate prevalence of pneumoconiosis, asthma, and chronic bronchitis due to sustained dust exposure. Systemic challenges- ranging from methodological deficiencies in impact assessment and weak regulatory enforcement to socio-economic imperatives privileging short-term gains and technical barriers in pollution abatement and land restoration- have impeded effective mitigation. Although some organized sector miners benefit from healthcare provisions and growing hazard awareness, these measures remain insufficient relative to the scale of risk. Achieving sustainable coal mining in India thus necessitates a rigorous, multi-dimensional strategy: fortifying legal and regulatory frameworks, ensuring robust enforcement and transparency, fostering substantive community engagement in governance and benefit-sharing, investing in advanced environmental technologies for

pollution control and land reclamation, and expanding healthcare infrastructure with proactive occupational health surveillance- collectively enabling a more equitable balance between India's energy imperatives and the imperatives of environmental stewardship and public health

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