IMPROVING AIR QUALITY THROUGH SUSTAINABLE MINING

Report | June 2025

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IMPROVING AIR QUALITY THROUGH SUSTAINABLE MINING

Compliance and Performance Assessment in Dhanbad's Coal Sector

Report I June 2025

ACKNOWLEDGEMENT

The author would like to express sincere gratitude to all those who contributed to the preparation of this report. This study is the outcome of a collaborative initiative focused on promoting sustainable practices and environmental improvements across the coal mining sector in Dhanbad City. We extend our sincere gratitude to all those who contributed to making this effort meaningful and impactful.

We are especially thankful to Dhanbad Nagar Nigam for its unwavering support and coordination throughout this exercise. We are deeply grateful to Mr. Raviraj Sharma, Municipal Commissioner, for his vision and leadership in championing initiatives that enhance environmental stewardship and industrial responsibility in the region.

We also appreciate the proactive engagement of the mining units—including Bharat Coking Coal Limited (BCCL), Tata Steel, and others—whose cooperation and openness to share information played a crucial role in the success of this effort. A special note of thanks to the survey and field teams from IIT-ISM Dhanbad and Asar Social Impact Advisors. Their dedication, technical expertise, and commitment to detail helped bring out valuable insights and practical recommendations that can support long-term environmental improvements.

This collaborative effort stands as a testament to what is possible when local governance, industry, and knowledge institutions come together with a shared commitment to a healthier and more sustainable future for Dhanbad.

CONTRIBUTING TEAM

Author:

Prof. Suresh Pandian Elumalai
Associate Professor
Department of Environmental Science and Engineering,
IIT (ISM) Dhanbad

Ankita Jyoti
Program Lead
Asar

Survey Team:

Govind Rajan
Asmita
Prateek
Satyam Jha

Design:

Penmi Rungsung

MESSAGE FROM THE DEPUTY COMMISSIONER, DHANBAD

ADITYA RANJAN, IAS

Deputy Commissioner
- Cum -
District Magistrate
Dhanbad

DHANBAD
☎ : 0326-2312401 (O)
: 0326-2312601 (R)
Mob. : 9471191601
Fax : 0326-2312602
E-mail : dhanbad.dc@gmail.com
: dc-dha@nic.in

Letter No. : 401/गो०, **Message from District Collector** Date : 03/06/2025

The district of Dhanbad has long stood at the forefront of India's energy economy. As home to some of the richest coal reserves in the country, our region has played a vital role in powering progress. Today, we are embracing the next phase of that journey—one where economic growth is balanced with environmental responsibility, and where mining operations are not just productive but also sustainable and health-conscious.

The report, *"Improving Air Quality Through Sustainable Mining,"* is a vital step in this direction. It reflects the proactive leadership of the Dhanbad Municipal Corporation in initiating an assessment to promote sustainable mining and improved air quality in the city. Through detailed assessments, data analysis, and site-level observations, it presents a clear picture of where we stand—and more importantly, where we can go from here.

What is especially encouraging is that the report not only identifies existing gaps in dust management but also outlines a set of progressive, actionable measures that can significantly reduce dust emissions from mining operations. These include improved road maintenance, better management of overburden, controlled transportation systems, greener buffer zones, and stricter adherence to environmental norms across the value chain. These interventions offer a practical pathway for transforming mining practices in Dhanbad and protecting the health of residents, particularly those living near active mine sites.

As District Collector, I see this report as a blueprint for moving from compliance to leadership. It calls for strengthening monitoring systems, enhancing accountability, and mainstreaming dust mitigation into every stage of the mining lifecycle. Most importantly, it signals a shift in mindset—towards long-term environmental stewardship, shared responsibility, and better coordination among government departments, industry players, and civil society.

The district administration remains fully committed to this agenda. Together, we can ensure that Dhanbad becomes a beacon of responsible mining—where economic prosperity goes hand in hand with clean air, healthy communities, and a sustainable future.

Aditya Ranjan, IAS
DeputyCommissioner, Dhanbad

FOREWORD FROM THE MUNICIPAL COMMISSIONER, DHANBAD

Office of the
Dhanbad Municipal Corporation,

दूरभाष :–18008904160 ई–मेल : dhanbadmunicipalcorporationadm@gmail.com

Foreword

Air pollution remains one of the most pressing challenges that cities across India face today. Dhanbad, with its rich coal reserves and vibrant mining industry, is no exception. While mining has significantly contributed to the economic growth of our region, it has also posed serious environmental challenges—particularly in terms of air quality.

The present study, *"Improving Air Quality Through Sustainable Mining,"* comes at a crucial juncture in our collective efforts to address air pollution. With the coal mining sector identified as the primary source of particulate matter (PM) emissions in the region, it is imperative to assess whether current practices comply with environmental regulations and to explore what a truly sustainable model of mining could look like for Dhanbad. This report helps lay that foundation—not only by evaluating compliance but also by presenting a broader vision for responsible and future-ready mining.

This report does more than assess the current situation—it also examines the effectiveness of existing mitigation measures at coal mine sites. The findings underscore the need for stricter adherence to air pollution control guidelines. Compliance with these regulations is not merely a legal obligation; it is a moral and social responsibility to ensure that our communities are not exposed to preventable health risks.

Furthermore, the report introduces a performance grading system that identifies areas for improvement and provides clear, actionable recommendations. In doing so, it lays the groundwork for continuous improvement and innovation in the sector.

The Dhanbad Municipal Corporation is fully committed to supporting this transition. We believe that cleaner air and a thriving industrial economy are not mutually exclusive. With greater coordination between government, industry, and academic institutions, we can accelerate the adoption of best practices across all mining operations. This study marks an important step in that direction, and I strongly urge all stakeholders—from policymakers to mining operators—to engage with its insights and act upon its recommendations.

Together, we must ensure that Dhanbad leads the way in responsible mining and becomes a model for how mining industries can thrive without compromising the health and well-being of our citizens.

(Ravi Raj Sharma)
Municipal Commissioner,
Dhanbad Municipal
Corporation

EXECUTIVE SUMMARY

Air pollution has emerged as a critical environmental and public health challenge in India, with urban areas experiencing particularly severe impacts. Among the primary contributors to this escalating crisis are emissions from industrial processes, vehicular traffic, construction-related dust, and coal mining activities. Dhanbad, often referred to as the "Coal Capital of India," exemplifies the complex intersection of industrial development and environmental degradation. While its abundant coal reserves have long underpinned the city's economic growth and industrial prominence, they have also led to significant and sustained air quality deterioration.

The region is surrounded by a dense concentration of coal washeries, coking coal industries, steel plants reliant on coked coal, and thermal power stations. Crucially, these pollution-intensive industries are not confined to the outskirts of the city but are also embedded within the urban fabric. Within the jurisdiction of Dhanbad Municipal Corporation, there are 32 Red Category and 19 Orange Category industrial units - both classifications denoting high levels of environmental risk and pollution. Notably, 31 out of the 55 municipal wards in Dhanbad fall in or around active mining zones, placing a substantial segment of the city's population in immediate proximity to high-pollution industrial and mining operations.

As a non-attainment city under the National Clean Air Programme (NCAP), Dhanbad Municipal Corporation has undertaken a series of initiatives aimed at mitigating air pollution. With mining being the most significant contributor to air pollution, this study forms an integral part of the Corporation's broader effort to deepen its understanding of air quality challenges and develop a targeted, evidence-based strategy for sustainable air quality management.

The purpose of this study was to evaluate air quality management practices, identify potential gaps in the coal mines, and recommend measures to enhance dust suppression and air quality management within the coal mining sector in Dhanbad. A total of eight coal mines, representing a diverse mix of open-cast, underground, and mixed mining operations, were selected. Adopting a sample-based site survey methodology, the study aims to generate empirical insights into the effectiveness of dust mitigation measures currently in place across operational mines.

The study also draws upon national and international examples of sustainable mining practices that have proven effective in reducing emissions. These practices will inform the development of a strategic framework tailored to the unique environmental and socio-economic context of Dhanbad.

Site Selection:

The city of Dhanbad is encircled by around 112 coal mines, which together produce approximately 27.5 million tonnes of coal each year and as on August 2021, the state of Jharkhand contributed to 16% of India's coal production. The all-India coal production in the year 2023-24 was 997.826 million Tonne (MT) in comparison to 893.191 MT in the year 2022-23 with a growth of about 11.71%. The city of Dhanbad is surrounded by about 112 coal mines with a total production of 27.5 million tonnes, generating an annual income of 7,000 crores. These mines are managed by several organizations, including BCCL, Tata Steel, Eastern Coalfields Limited (ECL), and the Indian Iron and Steel Company (IISCO). We reached out to 10 of these mines, and first 8 of them have responded, as listed below.

Site location	Category of mine	Abbreviations
Moonidih colliery	Underground Mine	U1
Gopalichuck OCP	Open Cast Mine	O1
Baghmara	Mixed Type	M1
Damoda Colliery	Open Cast Mine	O2
Gondudih Kusunda colliery	Open Cast Mine	O3
Amalgamated Keshalpur West Munidih colliery	Mixed Type	M2
E. J Area colliery	Mixed Type	M3
Dahibari Basantimata colliery	Open Cast Mine	O4

Table: Categorization of the selected coalmines as per the mining method for field visit and site abbreviations.

The study aims to:

a. Compliance Assessment: To evaluate the extent to which coal mining operations in the city adhere to existing environmental guidelines and regulatory frameworks intended to control air pollution emissions.

b. Real-Time Measurement of PM in Coal Mine Microenvironments (MEs): Monitoring of particulate matter (PM) concentrations in different microenvironments within coal mine areas to identify the contribution of specific mining activities to PM emissions.

c. Performance Evaluation of Coal Mines: Development of a structured grading system to assess the effectiveness of various dust mitigation measures across mining units.

d. Recommendations and Way Forward:

The study employed a multi-faceted approach, which included information gathering through questionnaires, site visits, and one-on-one meetings. A detailed survey questionnaire, developed in accordance with relevant environmental regulations, was distributed to mine authorities. After reviewing the responses, site visits were conducted to perform on-site evaluations, measure particulate matter levels, and assess the implementation of dust suppression practices.

The survey aimed to evaluate the mines based on the following key parameters:

- Emission Source Assessment
- Air Quality Monitoring
- Dust Control Measures
- Equipment and Maintenance
- Operational Practices
- Impact Assessment
- Passive Control Measures

The table outlines a structured approach to assessing the status and effectiveness of control measures within a system or process. Each measure is evaluated based on its availability and operational status, and a corresponding score is assigned to reflect its level of implementation and reliability. The highest score of 1 is given when a control measure is both available and fully functional, indicating optimal compliance and effectiveness. A score of 0.5 is assigned when the control measure exists but is not currently operational, highlighting a partial implementation that may still pose a risk. If the control measure is not yet available but is in the process of being procured or implemented, it receives a score of 0.25, signifying intention and planning without current functionality. The lowest score, 0, is reserved for situations where no reliable information is available; this includes cases where the measure is entirely absent, the data is faulty, or the information provided is irrelevant. The corresponding codes and abbreviations, Y for "Yes," NOP for "Not Operational," P for "Proposed," and NA/FD/DI for "Not Available," "Faulty Data," or "Data Irrelevant," serve as standardised indicators for quick reference and consistent reporting.

Availability of Measures	Code & their abbreviations	Scoring factor
Control measures are available and functioning properly	Yes (Y)	1
Control measures are available but not operational	Not Operational (NOP)	0.5
Control measure is not available, but its procurement is in process	Proposed (P)	0.25
Lack of information: The Measure is not available at all, or Faulty data is reported, or Irrelevant data is reported	Not Available (NA)/ Faulty Data (FD)/ Data Irrelevant (DI)	0

Table: Allocation of scoring factor for the assessment of dust control-related measures adopted by the coal mines.

In addition to scores, equal weightage is assigned to each mitigation measure to sum the total value on a 1-point scale. The scores are then multiplied by their corresponding weightage. The final scores allow for a comparison of performance across different mines. This enables mines to assess the relative effectiveness of various mitigation measures, helping them identify areas for improvement and take appropriate action.

In addition to evaluating dust control practices, the study also sought to understand the coal production and transportation processes within the reviewed mines, with a specific focus on how these activities contribute to dust emissions and air quality. The distribution of coal from each mining unit to various sectors, such as washing plants, power plants, and local vendors, was also assessed.

Real-time particulate matter (PM) measurements were utilized to identify the specific mining activities most responsible for PM emissions and evaluate the effectiveness of existing dust control measures.

KEY FINDINGS

1. Observations For Dust Mitigation Measures

The assessment of mitigation measures across the eight selected coal mines in Dhanbad revealed significant gaps and inconsistencies in the implementation of dust and emission control practices. Continuous Ambient Air Quality

Monitoring Stations (CAAQMS) were operational only at Moonidih Colliery, though not functional in most other locations. PM10 analysers were installed in some mines, but data reliability was an issue in several cases. While water sprinklers and fog cannons were widely reported as deployed, operational inconsistencies and non-functional equipment were observed at a few sites. Green belt development and roadside plantation data were either unavailable or irrelevant, indicating weak vegetation-based control strategies.

Critical interventions such as wet drilling and wheel washing were largely absent or inconsistently implemented across the sites. Notably, OB (Overburden) dump management practices were present in a few mines but absent in others, highlighting a need for better standardization. Overall, the observations point to fragmented and uneven adoption of mitigation measures, with several mines lacking basic air quality management infrastructure and practices.

Mitigation Methods	Weightage	U1	O1	M1	O2	O3	M2	M3	O4
CAAQMS	0.1	NOP	NOP	P	NA	P	NA	P	NA
PM10 ANALYSER	0.1	FD	Y	Y	Y	Y	Y	Y	NA
Green belt	0.1	DI	NA	Y	NA	Y	NA	Y	NA
Road side plantation	0.1	NA	Y	Y	NA	Y	Y	Y	NA
Water sprinklers/tankers	0.1	Y	Y	Y	Y	Y	Y	Y	Y
Fog cannon	0.1	Y	Y	Y	Y	Y	NOP	Y	Y
Coal handling plant	0.1	NA	NA	NA	NA	Y	NA	NA	NA
Wet drilling	0.1	Y	Y	Y	Y	Y	Y	Y	NA
Wheel washing	0.1	P	NOP	Y	NA	NA	NA	NA	NA
OB dump management	0.1	NA	Y	Y	NA	Y	NA	Y	Y

Table: Observations recorded for each of the eight mining sites, based on various mitigation measures implemented to control dust and pollution.

Mitigation Methods	Weightage	U1	O1	M1	O2	O3	M2	M3	O4
CAAQMS	0.1	0.05	0.05	0.025	0	0.025	0	0.025	0
PM 10 ANALYSER	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0
Green belt	0.1	0	0	0.1	0	0.1	0	0.1	0
Road Side plantation	0.1	0	0.1	0.1	0	0.1	0.1	0.1	0
Water sprinklers/tankers	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fog cannon	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.1	0.1
Coal handling plant	0.1	0	0	0	0	0.1	0	0	0
Wet drilling	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0
Wheel washing	0.1	0.025	0.05	0.1	0	0	0.1	0	0
OB dump management	0.1	0	0.1	0.1	0	0.1	0	0.1	0.1
Composite Score		**0.375**	**0.7**	**0.825**	**0.4**	**0.825**	**0.45**	**0.725**	**0.3**

Table: Scoring for each of the eight mining sites, based on various mitigation measures implemented to control dust and pollution.

An analysis of the composite scores for dust mitigation practices across the eight selected coal mines reveals considerable variability in implementation and compliance levels. The highest composite score of Baghmara mines and Gondudih Kusunda colliery scored (0.825), followed by EJ colliery & Gopalichak OCP (0.725 & 0.7 respectively) recorded reflecting relatively better adoption of dust suppression measures such as water sprinkling, fog cannons, PM10 analysers, wet drilling, wheel washing, and overburden (OB) dump management. Amalgamated Keshalpur (0.45), Damoda Colliery (0.4) and Moonidih Colliery (0.375) also showed moderate levels of compliance, though notable gaps remain in key areas like green belt development, and coal handling infrastructure.

In contrast Dahibari Basantimata scored significantly lower (both 0.3), indicating a lack of basic dust mitigation infrastructure and practices. Commonly missing measures across these lower-performing sites included the absence of CAAQMS, green belts, roadside plantations.

Coal Mines	Score out of 1	Potential Areas for Improvement
Moonidih Colliery	0.375	PM 10 ANALYSER, Green belt, Road side plantation, OB dump management, Coal handling plant
Gopalichuck OCP	0.7	Green belt, Coal handling plant, Wheel washing
Baghmara	0.825	CAAQMS(Proposed), Coal handling plant,
Damoda Colliery	0.4	CAAQMS, Green belt, Road side plantation, Coal handling plant, Wheel washing, OB dump management
Gondudih Kusunda Colliery	0.825	CAAQMS(Proposed), Wheel washing
Amalgamated Keshalpur	0.45	CAAQMS, Green belt, Coal handling plant, Wheel washing, OB dump management
E.J Area Colliery	0.725	CAAQMS(Proposed), Coal handling plant, Wheel washing,
Dahibari Basantimata	0.30	CAAQMS, Green belt, Road side plantation, Coal handling plant, Wet drilling, Wheel washing, PM 10 ANALYSER

Table: Potential area for improvement on the basis of scoring.

2. Observations for coal distribution and its mode of transportation

The analysis of coal distribution routes from the selected mines reveals significant reliance on road transport, which has direct implications for dust generation and local air quality.

The distribution of coal from each mining unit to various sectors - such as washing plants, power plants, local vendors, and others - has also been evaluated and is presented below.

- Road transport is the primary mode of coal distribution, serving various destinations, including washery, power plants, local vendors, and other purposes.
- Railway Transport plays a dominant role in supplying power plants, particularly from Baghmara (85%), Gondudih Kusunda (48%), and Amalgamated Keshalpur (80%).
- Conveyors are primarily used in washery distribution at Moonidih colliery (86.88%).

Coal Distribution	Route	U1 (TPD)	O1 (TPD)	M1 (TPD)	O2 (TPD)	O3 (TPD)	M2 (TPD)	M3 (TPD)	O4 (TPD)
Washery	Road	182.22	843.79	-	NA	-	392.24	NA	NA
	Railway	-	-	-	NA	-	-	NA	NA
	Conveyors	1206.66	-	-	NA	-	-	NA	NA
Powerplant	Road	-	68.39	-	NA	1477.26	392.24	NA	NA
	Railway	-	-	2273.58	NA	2215.88	6275.8	NA	NA
	Conveyors	-	-	-	NA	-	-	NA	NA
Local Vendor	Road	-	-	491.22	NA	-	784.5	NA	NA
	Railway	-	-	-	NA	-	-	NA	NA
	Conveyors	-	-	-	NA	-	-	NA	NA
Any Other	Road	-	-	-	NA	923.29	-	NA	NA
	Railway	-	-	-	NA	-	-	NA	NA
	Conveyors	-	-	-	NA	-	-	NA	NA
Total Production (TPD)		**1388.88**	**910.34**	**2674.8**	**NA**	**4618.43**	**7844.74**	**NA**	**NA**

Table: Different transportation modes for the distribution of produced coal by mines to the different consumers (in Tonnes Per Day, i.e., TPD).

The classification of transportation modes across various sectors has been conducted to provide a detailed understanding of the coal distribution system. This approach allows for a more thorough analysis of the transportation methods, their efficiency, and their environmental impact, enabling better strategies for mitigation and improvement in the coal supply chain.

The table below outlines the mode-wise coal transportation to various sectors from the mines under study.

Sector	Mine	Mode of Transport	Percentage
Washery Distribution	Gopalichuck OCP	Road	92.69%
	Moonidih Colliery	Road	13.11%
	Amalgamated Keshalpur	Road	5%
	Moonidih Colliery	Conveyor	86.88%
Power Plant Distribution	Gopalichuck OCP	Road	7.30%
	Gondudih Kusunda	Road	32%
	Amalgamated Keshalpur	Road	5%
	Gondudih Kusunda	Railway	48%
	Amalgamated Keshalpur	Railway	80%
	Baghmara	Railway	85%
Local Vendor Supply	Baghmara	Road	15%
	Amalgamated Keshalpur	Road	10%
Other Consumers	Gondudih Kusunda	Road	20%

Table: Percentage distribution of produced coal by various transport routes from each mine.

For washery distribution, Gopalichuck OCP supplies the highest amount of coal via road, whereas Moonidih Colliery utilizes both road and conveyor systems for transportation. In terms of power plant distribution, Gondudih Kusunda employs a balanced supply chain, using both road and railway modes. Meanwhile, Amalgamated Keshalpur and Baghmara emerge as major suppliers via railway, contributing around 80% and 85% respectively.

For local vendor supply, Baghmara is the only mine supplying 15% of its production to local vendors via road, while Amalgamated Keshalpur provides 10% through the same mode. Additionally, Gondudih Kusunda distributes 20% of its production via road to other consumers, highlighting the significance of road transport across various end-use sectors.

Further, the coal distribution data reveals varied patterns across the five mines. Baghmara and Gondudih Kusunda primarily supply coal to power plants (85% and 80% respectively), with the remainder going to local vendors. Amalgamated Keshalpur also focuses on power plants (85%), while supplying small portions to local vendors (10%) and washeries (5%). Gopalichuck OCP and Moonidih Colliery are predominantly washery-focused, with 92.6% and 100% of their coal going to washeries, respectively. Data for Damoda Colliery, E.J Area Colliery, and Dahibari Basantimata is not available.

Coal Mines	U1	O1	M1	O2	O3	M2	M3	O4
Washery Distribution	100%	92.69%	0%	NA	0.00%	5%	NA	NA
Power Plant Distribution	0%	7.31%	85%	NA	80%	85%	NA	NA
Local Vendor Supply	0%	0%	15%	NA	0%	0%	NA	NA
Other Consumers	0%	0%	0%	NA	20%	10%	NA	NA

Table: A mix of single-sector and multi-sector supply strategies among the coal mines.

3. Real-Time Measurement of PM

The particulate matter (PM) monitoring data across various coal mine sites reveals critical insights into the air pollution levels associated with specific mining activities. Amalgamated Keshalpur West Munidih Colliery shows alarmingly high PM concentrations, especially at the crusher point, recording PM_{10} at 3123.60 µg m-3 and $PM_{2.5}$ at 742.56 µg m-3, far exceeding all other sites and suggesting extremely poor air quality and potential exposure risks for workers. Even its haul road shows elevated levels (PM_{10}: 494.50 µg-m-3), indicating substantial dust emissions from internal transport routes.

Gondudih Kusunda Colliery and Damoda Colliery also exhibit high PM_{10} levels at their excavation points, at 348.70 µg m-3 and 264.06 µg m-3respectively. Gondudih, in particular, has a significantly high $PM_{2.5}$ concentration of 160.48 µg m-3, suggesting a large share of fine particulate matter, which poses greater respiratory health risks. The $PM_{2.5}$ to PM_{10} ratio here is 0.46, indicating a substantial proportion of respirable particulates.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Siding locations	1 minute	119.87	75.57
Haul road	1 minute	153.90	80.23
In the Garden	1 minute	104.23	73.90

Table: Activity-wise measured PM (µg m-3) using the GRIMM at the Baghmara coal mines.

On the other hand, Baghmara, E.J. Area, and Dahibari Basantimata exhibit comparatively lower PM levels, with average PM_{10} concentrations of 126, 131.95, and 194.49 µg m-3, respectively. Among them, Baghmara shows the highest $PM_{2.5}$ to PM_{10} ratio (0.61), indicating a finer particle mix that could more easily penetrate deep into the lungs. E.J. Area follows with a ratio of 0.51, also suggesting a significant presence of fine particulates despite lower overall concentrations.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Excavation point	1 minute	264.06	77.20

Table: Activity-wise measured PM (µg m-3) using the GRIMM at the Damoda Colliery coal mines.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Crusher point	1 minute	3123.60	742.56
Haul Road	1 minute	494.50	220.90

Table: Activity-wise measured PM (µg m-3) using the GRIMM at the Amalgamated Keshalpur West Munidih colliery.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Coal washery	1 minute	205.82	81.52
OB dump reclamation site	1 minute	183.16	78.98

Table: Activity-wise measured PM(µg m-3) using the GRIMM at the Dahibari Basantimata coal mines.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Excavation point	1 minute	348.70	160.48

Table: Activity-wise measured PM(µg m-3)using the GRIMM at the Gondudih Kusunda Colliery coal mines.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
OB Dump Excavation point	1 minute	131.95	67.50

Table: Activity-wise measured PM(µg m-3) using the GRIMM at the E.J Area Colliery coal mines.

This report highlights the ongoing challenges and emerging strategies for dust control within coal mining operations. The report identifies specific activities, such as coal processing, particularly at crusher plants and haul roads, as key sources of fugitive dust emissions. Notably, dust concentrations spike significantly during coal feeding into crushers, signalling a need for enhanced dust suppression measures. Effective mitigation techniques, such as enclosing crusher units and employing water sprays, have proven successful in reducing dust emissions. Similarly, regular water sprinkling and the use of durable road materials can mitigate dust emissions from haul roads.

Beyond dust control during coal production, the handling and transportation of coal represent significant sources of particulate emissions. The report advocates for the adoption of cleaner transportation methods, such as conveyors and railways, to minimize road dust emissions. Additionally, the handling of coal at various stages in the supply chain, particularly during transport to consumers like power plants and local vendors, requires closer attention.

The report also emphasizes the need for innovation in dust control solutions. The mining industry is gradually shifting towards more sustainable and efficient dust management technologies, such as remote sensing, dust-resilient pavements, and stockpile covers, all of which can significantly reduce fine particulate matter emissions.

FUTURE DIRECTIONS

- The study finds that variations in dust concentration within coal mines are activity-specific. Partial pavement of haul roads, coupled with regular watering and fogging, is an effective way to manage dust emissions. The highest levels of particulate matter (PM) were recorded at the coal crusher point. A significant spike in PM concentration occurs immediately when coal is fed into the crusher, indicating rapid dust generation. To mitigate this, dust suppression measures such as continuous water sprinkling during unloading and the use of tall curtains (isolation) around the crusher plant have proven effective in containing dust spread in the surrounding environment. Additionally, the use of wind barriers and suction hoods is proposed to capture coal dust emissions during crusher operations within the coal mine premises.

- To reduce the spread of coal dust in local areas, a dedicated road network for coal transport is recommended. Establishing a centralized coal processing hub away from mine sites is also advised. Furthermore, relocating or phasing out the distribution of coal washeries and coke-producing units to a common hub outside residential areas is recommended.

- Regulatory authorities should mandate that mining and coal-dependent industries submit Business Responsibility and Sustainability Reports (BRSR) and Global Reporting Initiative (GRI) reports. These reports should be submitted on time and made publicly accessible.

- Dhanbad is surrounded not only by coal mines but also by allied industries such as coking coal plants and other small-scale coal-dependent industries, which significantly contribute to the city's poor air quality. Therefore, it is recommended that a separate study be conducted to assess the percentage of coal consumption by these industries, along with an analysis of the supply chain.

- Particulate matter generated during coal mining is just one component of total emissions, which also include emissions from coal transport, processing, and combustion by allied industries located around the mines. While PM emissions from production are largely contained within mine premises, dust spread into the city and residential areas mainly arises from coal transportation. Therefore, effective air quality management must include controlling emissions across the entire supply chain, especially from road transport of coal to consumers such as washeries, coke producers, steel plants, and power stations.

- Additionally, the use of coal by the public for residential cooking and by small-scale industries such as restaurants and brick kilns also requires attention.

- A dedicated analysis is needed, focusing on emissions from mine fires & emissions from the consumption of coal by the local public for residential and commercial purposes.

- Road transport is a major contributor to overall pollution levels; therefore, exploring alternative modes for coal transportation, other than road, is required.

- A detailed scientific study is needed to measure the dust profile in and around the coal mine during the mine's operational time and during non-operational time

- A detailed scientific study is needed to quantify the dust profile in and around a coal mine during both operational and non-operational periods, to better understand the impact of coal production and transport on air quality. Another study should focus specifically on dust generated from overburden dumps due to wind action.

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LIST OF ABBREVIATIONS

NCAP
National Clean Air Programme

MoEFCC
Ministry Of Environment, Forest, And Climate Change

PM
Particulate Matter

NAAQS
National Ambient Air Quality Standards

DMC
Dhanbad Municipal Corporation

Y
Yes (Available And Functioning Properly)

NA
Not Available

DG
Diesel Generators

OB
Overburden

CHP
Coal Handling Plant

PPE
Personal Protective Equipment

MTPA
Metric Tonne Per Annum

OCP
Open Cast Project

UG
Under Ground

GB
Green Belt

HEMMs
Heavy Earth Moving Machinery

CHP
Coal Handling Plant

RLS
Rapid Loading System

FMC
First Mile Connectivity

BCCL
Bharat Coking Coal Limited

MGR
Merry Go Round Loading System

BRSR
Business Responsibility And Sustainability Reports

GRI
Global Reporting Initiative

1. INTRODUCTION & OBJECTIVES

Air pollution has become a significant environmental and public health issue in India, particularly in urban centres. Key contributors to this growing crisis include industrial, vehicular and dust emissions from coal mining activities. The main emissions contributing to air pollution include particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NOx), and carbon dioxide (CO_2).

Particulate matter (PM) is the general term used for a mixture of solid particles and liquid droplets found in the air. Some particles are large or dark enough to be seen as soot or smoke, while others are so small that they cannot be seen with the naked eye. These small particles, which come in a wide range of sizes, originate from many different stationary and mobile sources as well as natural sources. Fine particles—those less than 2.5mm (i.e., $PM_{2.5}$) - are a result of fuel combustion from motor vehicles, power generation, industrial facilities, and residential fireplaces and woodstoves. Coarse particles - those larger than 2.5 mm but classified as less than 10 mm (i.e., PM_{10}) - are generally emitted from sources such as vehicles traveling on unpaved roads, materials handling, crushing and grinding operations, and windblown dust. In other cases, gases such as SO_2, NOx, and VOCs react with other compounds in the air to form fine particles.

Dhanbad is often called the coal capital of India - and for good reason - but it is also grappling with a growing air pollution crisis. The land here is rich with coal, a resource that has long shaped the city's identity and fueled its economic development. Over the years, the city has become a hub for coal-dependent industries that intensify its environmental burden. Surrounding Dhanbad are numerous coal washeries, coking coal industries, steel plants reliant on coked coal, and thermal power stations using both washed and unwashed coal. While these industries are crucial for regional and national growth, they also emit large volumes of air pollutants - including particulate matter (PM), sulfur dioxide (SO_2), nitrogen oxides (NOx), and carbon monoxide - contributing to a continuous cycle of degraded air quality and posing serious health risks for local communities.

The region is surrounded by other dependent industries listed as -

1. Coal Washeries
2. Coking Coal industries
3. Steel Industries using Coked coal
4. Thermal Power plants using washed/unwashed coal.

Industry Classification and Distribution

Highly polluting industries (17 categories): There are **4** highly polluting industries of 17 categories.

Red category industries (54 categories): There are **586** industries of 54 categories.

Orange and Green category industries: There are around **1000** industries under these categories.

Grossly polluting industries: High density of Coal mines **(103)** Coal washeries **(8)** Captive Thermal power plants **(3)** Beehives coke oven plants **(126)** Soft coke plants **(25)** Refractory plants **(72)**, Coke briquette plants **(25)**, Stone crusher **(110)**, Brick Kilns **(118)**[1].

However, it is important to note that these industries are equally present within the urban limits. Dhanbad, within its municipal boundaries, hosts a considerable number of highly polluting industries—comprising 32 Red Category and 19 Orange Category units.. Strikingly, 31 out of the 55 wards under the Dhanbad Municipal Corporation fall in or around mining zones, placing a significant

1 (source-ACTION PLAN FOR CLUSTERS OF DHANBAD, https://cpcb.nic.in/displaypdf.php?id=REhBTkJBRC5wZGY=)

portion of the city's population in close proximity to industrial and mining-related activities. Bharat Cooking Coal Limited (BCCL), Steel Authority of India (SAIL), and Tata Steel operate through 17 mining and washery units spread across the 55 wards of Dhanbad Nagar Nigam, where coal extraction predominantly takes place through open-cast mining (OCM).

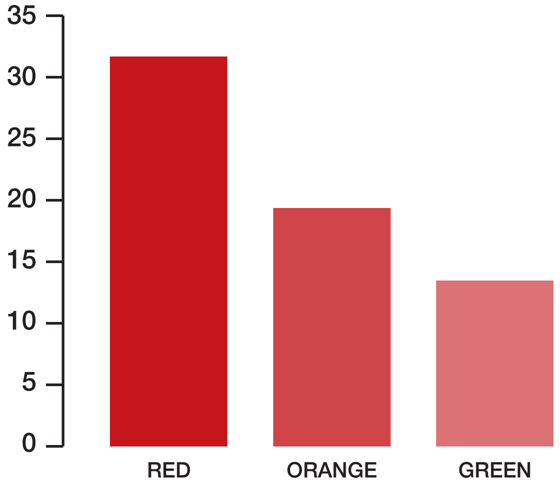


Figure 1: Category-wise Classification and Count of Industries in Dhanbad (Source: JSPCB)

Mining - particularly open-cast coal mining - is one of the most persistent and visible sources of air pollution in the city. Unlike other industrial activities that often take place away from residential zones, mining operates right next to where people live, go to school, and work, making the impact on daily life immediate and inescapable. Every stage of mining, from blasting and drilling to excavation and hauling, kicks up massive amounts of dust and releases harmful gases into the air. The dust burden from surface mining is far greater than that of underground mining. According to the World Bank Group, surface mining methods like contour and area mining release about 0.1 and 0.06 tons of dust per 1,000 tons of coal, while conventional and longwall underground methods emit significantly less - only 0.0006 and 0.01 tons, respectively.

However, the pollution doesn't stop at extraction. Transporting coal - mostly done by rail but also by truck, water, slurry pipeline, or conveyor - adds another layer of environmental damage. Fugitive dust emissions are common during loading, transit, and unloading. Even with improved handling practices, it is estimated that 0.02 percent of the coal loaded is lost as fugitive dust, and an equal amount is lost when it is unloaded. It is estimated that 0.05 to 1 percent of the coal is lost during transit. The actual amount depends on the mode of transit and the length of the trip, but it can be sizable, especially with unit train coal transit across the country. (Source: Clean Coal Engineering Technology by Bruce G Miller).

India has established a comprehensive legal and regulatory framework to address environmental risks associated with the mining sector, particularly in relation to air and water pollution. Coal mining operations are regulated under several key legislative instruments, including the Mines Act of 1952, the Coal Mines Regulations of 2017, the Air (Prevention and Control of Pollution) Act of 1981, and the Water (Prevention and Control of Pollution) Act of 1974. These statutes include specific provisions for monitoring, compliance, and environmental safeguards. Additionally, the Ministry of Coal has issued guidelines on **'Air Pollution Management Practices,'** which are reinforced by directives from the Ministry of Environment, Forest and Climate Change (MoEFCC). Despite the presence of these frameworks, it remains critical to evaluate the extent to which they are being effectively enforced and implemented. A thorough assessment is essential to identify gaps in compliance and to explore sustainable approaches for mitigating the long-term environmental impacts of coal mining activities.

As a non-attainment city under the National Clean Air Programme (NCAP), Dhanbad Municipal Corporation has been proactively implementing a range of mitigation measures to address its air quality challenges, with a particular focus on the mining sector, which continues to be the most significant source of emissions in the city. And this study forms part of a broader initiative led by the Dhanbad Municipal Corporation to better understand the city's air quality challenges and to develop a targeted strategy for effective air quality management, with a specific focus on dust and pollution arising from the mining sector.

The study will focus on evaluating the current compliance status of existing coal mines with established environmental guidelines related to the prevention and control of fugitive emissions from mining activities, utilizing a sample survey methodology. The report will also explore sustainable mining practices implemented both across the country and internationally, aimed at effectively minimizing emissions within the sector. It will provide a strategic framework, informed by these practices, to address the long-term air pollution challenges faced by the city - offering actionable insights that can be utilized by the municipal authorities and district administration for effective planning and implementation.

NCAP, India's flagship initiative for air quality improvement, is specifically designed to support non-attainment cities through a combination of regulatory actions, strategic planning, and localized interventions aimed at reducing particulate pollution levels.

1.1 OBJECTIVES

This study has been designed to provide actionable insights into the environmental performance of coal mining operations within Dhanbad, with a focus on air quality management. It aims to assess the current air pollution compliance status of coal mining operations within the jurisdiction of Dhanbad Municipal Corporation with existing environmental regulations, particularly those related to the prevention and control of fugitive emissions.

The study aims to:

a. Compliance Assessment: To conduct a comprehensive audit to evaluate the extent to which coal mining operations in the city adhere to the established guidelines, and the regulatory framework in order to control air pollution emissions.

b. Real Time Measurement of PM at Coal Mine Microenvironments (MEs): To measure particulate matter (PM) levels in various microenvironments of the coal mine area in real-time, and to identify the contribution of different activities to PM emissions.

c. Performance Evaluation of Coal Mines: To assign weightage to different mitigation measures and develop a grading system for evaluating the performance of coal mines based on the availability and effective functioning of these measures.

d. Recommendations and Way Forward: To develop a set of actionable recommendations aimed at promoting sustainable mining practices and improving air quality in the city.

2. METHODOLOGY

2.1 STUDY AREA

For the purpose of this study, eight coal mines within the jurisdiction of Dhanbad Municipal Corporation have been selected to evaluate their compliance with established environmental guidelines. The selected mines represent a diverse mix of open-cast, underground, and mixed mining operations, enabling a comprehensive assessment of dust mitigation measures across various mining methods. It also ensures a comprehensive environmental assessment, encompassing a range of operational scales and varying proximities to human settlements.

Figure 2: Geographical Location of Dhanbad in India.

The mines are situated at distances between 8 km and 47 km from Dhanbad city, providing a balanced representation of both urban-adjacent and more distant mining operations.

The eight mines included in the study are:

1. **Moonidih Colliery -** A prominent underground mine recognized for its extensive deep mining operations.
2. **Gopalichuck OCP -** An open-cast project (OCP) contributing to surface mining activities.
3. **Baghmara (Cluster III) Mines -** A group of mines under Cluster III, representing a mix of mining types.
4. **Damoda Colliery -** One of the key mining sites in the region.
5. **Gondudih Khas Kusunda Colliery -** A mine with a history of both underground and open-cast activities.
6. **Amalgamated Keshalpur West Mudidih Colliery -** A combined mining area contributing to coal production.
7. **Dahibari Basantimata Colliery -** Known for its mining operations in the area.
8. **E.J. Area (Cluster X) -** A cluster of mines forming part of the study.

Open Cast Mine (O)	Underground Mine (U)	Mixed Type (M)
Gopalichuck OCP (O1)	Moonidih Colliery (U1)	Baghmara (Cluster III) (M1)
Damoda Colliery (O2)		Amalgamated Keshalpur West Munidih Colliery (M2)
Gondudih Kusunda Colliery (O3)		E. J Area Colliery (M3)
Dahibari Basantimata Colliery (O4)		

Table 1: Categorisation of the selected coal mines as per the mining method.

CATEGORISATION ON THE BASIS OF MINING METHOD

Open Cast Mine

An open-cast mine (also known as an open-pit mine or strip mine) is a type of surface mining where minerals or rocks are extracted from the earth by removing large quantities of overburden (soil, rock, and other materials) above the ore body.
It involves digging down in a stepped manner, creating a large pit, which can become very deep over time.

Some key features of open-cast mining include:

a. **Large-scale excavation:** Big machines like draglines, shovels, and haul trucks are used to move the materials.

b. **Visible pits:** The mine creates large, visible holes in the landscape, which can sometimes be several hundred meters deep.

c. **Environmental concerns:** Open-cast mining can cause environmental damage, such as deforestation, habitat destruction, and water contamination.

It's the most cost-effective method when the material is located near the surface, but it can be much more disruptive to the environment compared to underground mining.

Underground Mines

An underground mine is a type of mining operation where resources, such as minerals or ores, are extracted from beneath the Earth's surface. Unlike open-pit or surface mining, which removes material from the surface, underground mining involves digging shafts, tunnels, or declines to reach the mineral deposits located deep underground.

There are various methods of underground mining, including: Drift mining, Shaft mining, Room and pillar mining and Cut and fill mining

Underground mining can be dangerous due to risks like tunnel collapses, rock falls, and toxic gas build up, so safety measures are critical.

Mixed type mine

A mixed-type mine refers to a mining operation that combines both surface mining and underground mining methods. This approach is used when a mineral deposit is located in a way that part of it is accessible near the surface, while the rest lies deeper underground.

This approach allows mining companies to maximise the extraction of valuable resources while minimising waste and cost.

The choice between using surface or underground methods depends on factors like the depth of the ore body, the type of ore, environmental concerns, and economic considerations.

2.2 STUDY DESIGN

The study employed a multi-faceted approach comprising online surveys, site visits, and one-on-one meetings to evaluate compliance across eight coal mines. A comprehensive survey questionnaire, informed by environmental regulations, was circulated to the mine authorities. After reviewing the responses, site visits were scheduled to conduct on-site assessments, measure particulate matter levels, and evaluate the implementation of dust suppression mining practices. The findings were systematically analyzed and consolidated into a detailed report.

Data was collected from individual coal mines through an online questionnaire survey.

The survey team conducted field visits and inspections at the coal mines.

Real-time particulate matter (PM) measurements were conducted using the GRIMM optical counter.

The online questionnaire responses were clarified in one-on-one meetings.

Factors influencing the air quality in coal mines.

Inter-comparison was between all the surveyed mines.

Performance Evaluation using Grading System.

Missing data was collected from individual units following the field visit.

Interpretation of the result.

Figure 3.Flow Diagram Illustrating the Key Steps Undertaken in the study.

2.2.1 SURVEY QUESTIONNAIRE

The survey questionnaire was developed based on environmental compliance standards from various mines and the Ministry's guidelines on air pollution and control. The questionnaire, formatted as a Google Form, was distributed to all the selected mines, and the concerned authorities were requested to provide their responses. The questions were kept clear and concise, serving as a preliminary assessment tool, while a more detailed evaluation was undertaken during the subsequent site visits.

Given that the study covered all three major mining methods - open-cast, underground, and mixed-type - potential sources of particulate emissions specific to each method were first identified.

The questionnaire was then tailored to include relevant queries addressing these emission sources, ensuring a comprehensive and method-specific evaluation of dust control practices across all mining types.

The questionnaire was structured around key parameters and thematic sections, as outlined in the table below:

Particulars
Emission Sources assessment
Air Quality Monitoring
Dust Control Measures
Equipment and Maintenance
Operational Practices
Impact Assessment
Passive Control Measures

Table 2:Selected Parameters and Sections chosen for the study.

Particulars	Sources
Emission Sources Assessment	(1.a) Dust generation sources (1.b) Combustion emissions sources (1.c) Blasting and coal mine fire emission sources
Air Quality Monitoring	(2.a) Ambient air quality (2.b) CAAQMS (real-time monitoring)
Dust Control Measures	(3.1) Enclosed cabs for equipment operators (3.1.a) Performance measures (3.1.b) Cab integrity (3.1.c) Filtration and pressurisation systems (3.1.d) Filter selection (3.1.e) Air intake and discharge locations (3.1.f) Internal dust sources (3.2) Dust control for highwall drills (3.2.a) Dry dust collection system (3.2.b) Wet drilling (3.3) Haul road dust control (3.3.a) Road construction (3.3.b) Traffic control (3.3.c) Water application (3.3.d) Chemical dust suppressants (3.4) Dust control at the primary dump (3.4.a) Enclosure of the primary dump (3.4.b) Water sprays at the primary dump (3.4.c) Activation of dust controls (3.5) Stockpile and preparation plant dust control
Equipment and Maintenance	(4.a) Heavy earth moving vehicle (tail pipe and non-tailpipe emission) (4.b) Other vehicles (4.c) Drilling and operation equipment (4.d) Maintenance and fuel consumption records (4.e) Registration and PUC of vehicle and other equipment
Operational Practices	(5.a) Work practices (5.a.i) Blasting techniques (5.a.ii) Coal handling procedures (5.b) Employee training
Impact Assessment	(6.a) Health and safety (6.a.i) Measures taken for health and safety of mine workers (6.a.ii) Measures taken for health and safety of people live around coal mine area (6.b) Environmental impact (including effects on local ecosystems and wildlife)
Passive control measures	(7.a) Public Grievances Redressal System (PGRS) % of air pollution related (7.b) complaints (7.c) Awareness & engagement practices (7.d) Measures taken for reducing piggy backing of coal and open burning Sapling and plantation

Table 3: Sub-Categories for Each Selected Evaluation Parameter.

Relevant notices by Ministry of coal regarding environmental management in coal mining

Open Cast Mine

Environmental management is a critical concern in the coal mining industry. In response, the Government of India, through the Ministry of Coal, which oversees all coal mine-related matters in the country, has been taking proactive steps to address environmental issues. These initiatives focus on enhancing the efficiency of coal transportation, reducing environmental hazards, and promoting sustainable mining practices. The following table summarises the relevant notifications issued by the Ministry of Coal, highlighting their key focuses and objectives, including advancements in coal evacuation systems, first mile connectivity (FMC) projects, and measures to mitigate surface fires and promote sustainable mining practices. The Ministry regularly issues notices aimed at controlling air pollution, and the relevant notices are summarised in Table below.

Table Ministry of Coal notifications and their key focusses

Notification	Study	Key focusses
01 DEC 2018 by PIB Delhi (Ministry of coal).	Efficient Transportation of Coal.	To enhance coal evacuation efficiency, Rapid Loading Systems, elevated closed belt conveyors, and MGR systems are being implemented at coal mines and power plants based on their distance from pitheads.
20 OCT 2022 by PIB Delhi (Ministry of coal).	Ministry of Coal takes up 68 First Mile Connectivity (FMC) Projects for Seamless Evacuation of Coal.	To upgrade mechanised coal transportation and loading system under 'First Mile Connectivity projects. Coal Handling Plants (CHPs) and SILOs with Rapid Loading Systems will have benefits like crushing, sizing of coal and speedy computer aided loading.
25 SEP 2023 by PIB Delhi (Ministry of coal)	Jharia Master Plan: Coal Ministry Efforts Bring Down Surface Fire Identified from 77 to 27 Sites.	Implementation of Scientific Measures Reduce fire surface area from 17.32 Sq Km to 1.80 Sq km.
22 JUL 2024 by PIB Delhi (Ministry of coal).	First Mile Connectivity Projects.	Before August, 2019, Coal India Limited (CIL) had established 20 First Mile Connectivity (FMC) projects of 151 MTY capacity. Since, August, 2019, CIL has identified additional 72 First Mile Connectivity (FMC) projects of 837.5 MTY Capacity. Out of these 72 projects, 15 projects of 200.5 MTY have been commissioned. Thus, as on date, total 35 FMC projects have been commissioned and are functional.
02 DEC 2024 by PIB Delhi (Ministry of coal).	Sustainable Mining Practices and Innovations.	Various environmentally sustainable measures include: • Greening Initiatives (Bio-Reclamation) • Eco-parks • Green Credit Programme • First Mile Connectivity (FMC) projects • Deployment of Blast free technology in coal mining.

2.2.2 SITE VISIT TO SELECTED MINES

After receiving responses to the questionnaire, the information was evaluated, and follow-up communication was initiated with the relevant mine authorities to schedule official site visits. The dates for these physical visits were finalised in coordination with the respective mining units. The responses were thoroughly reviewed to identify any unanswered questions, as well as to document the sustainable mining practices reported by each mine. In preparation for the field visits, an additional checklist was developed to ensure that all critical observations would be captured.

Mine Name	Date
Moonidih Colliery	03/12/2024
Gopalichuck OCP	03/12/2024
Baghmara (Cluster III) (Mixed Type)	12/12/2024
Damoda Colliery	17/12/2024
Gondudih Kusunda Colliery	18/12/2024
Amalgamated Keshalpur West Mudidih Colliery	20/12/2024
E. J Area Colliery	21/12/2024
Dahibari Basantimata Colliery	24/12/2024

Table 4: Timeline of Field Visits to Selected Mines.

After the site visit, additional data was gathered from the relevant mine authority to address the observations and concerns raised during the visit.

The follow up questions shared with the concerned persons were on:

- Onsite fuel consumption
- Onsite electricity consumption details
- DG sets detail
- Trips made for loading and unloading of coal
- Average coal produced per year (in million tonnes per annum)
- Average production per day (in tonnes per day)
- Percentage distribution of coal produced to different consumers (washery, powerplant, local vendors, etc)
- Distance travelled to deliver the coal to the respective consumer
- Production on the day of site visit

2.2.3 ONSITE PM MEASUREMENT

During the site visits, particulate matter (PM) levels were measured both onsite and along the roads leading to the mines using an Optical Particle Counter (GRIMM) using an Optical Particle Counter (GRIMM). This device measures parameters such as PM10, PM2.5, and PM1. The dust aerosol spectrometer and dust monitor (model 1.109) are compact, portable instruments designed for continuous monitoring (Interval of every 1 minute) of airborne particles, as well as for analysing particle count distribution. The data is displayed both as particle concentration in particles per liter and as mass concentration in μg/m³.

3. OBSERVATIONS AND INTERPRETATION OF DATA

3.1 KEY OBSERVATIONS

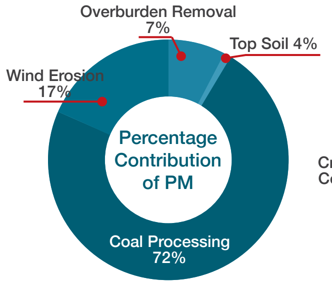
The information gathered from both the survey, site visits, and one-on-one meetings has been categorized into three distinct categories for further analysis and evaluation.

3.1.1 OBSERVATIONS FOR DUST MITIGATION MEASURES

Dust generation remains a major environmental challenge in coal mining, as it occurs not only at the periphery of mining operations but throughout the entire process, from extraction to end-use. Key sources of dust emissions include drilling and blasting, coal cutting and loading, crushing and screening, as well as transportation and stockpiling. Furthermore, activities such as overburden removal, vehicle movement on unpaved roads, and wind erosion over dry coal and overburden dumps exacerbate airborne particulate matter. Dust is also generated during coal washing and drying operations.

The percentage contributions of various mining activities to dust emissions are presented in Figures 4, 4a, 4b, and 4c (Mrinal K. Ghose, 2007; Singh & Tiwari, 2016; Joshi et al., 2020).

Figure 4: Percentage contribution of total particulate matter with respect to various mining activities



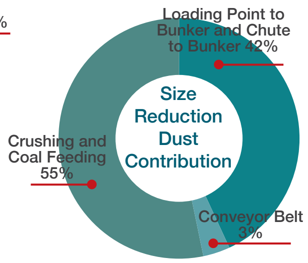
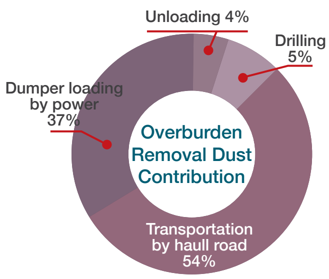


Figure 4a: Overburden removal dust contribution

Fig. 4c: Size reduction dust contribution



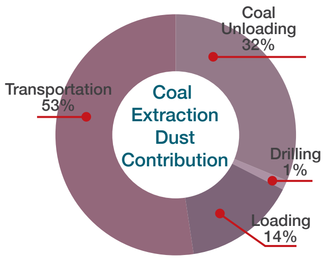


Fig.4b: Coal extraction dust contribution

Here are the main sources of dust in coal mining activities:

Drilling and Blasting: The use of explosives in coal seams generates fine dust and rock particles that become airborne, especially in open-cast mines.

Coal Cutting and Loading: Mechanical equipment like continuous miners releases dust during the extraction and loading of coal into trucks or conveyors.

Transportation and Stockpiling: Moving coal via trucks, trains, or belts and dumping it into stockpiles causes friction and handling-related dust emissions.

Crushing and Screening: When coal is crushed and sorted by size, fine particles are released, contributing significantly to dust pollution.

Wind Erosion: Dust is picked up by wind from uncovered coal stockpiles or overburden dumps, particularly in dry or poorly managed areas.

Coal Washing: The drying process post-washing can emit dust into the air if not properly controlled.

Vehicle Traffic: Movement of heavy vehicles on unpaved or dusty surfaces stirs up dust, adding to ambient particulate matter.

Overburden Removal: Excavation and movement of soil and rock layers above coal seams create dust, particularly during dry weather or high activity phases.

The table outlines a structured approach to assessing the status and effectiveness of control measures within a system or process. Each measure is evaluated based on its availability and operational status, and a corresponding score is assigned to reflect its level of implementation and reliability. The highest score of 1 is given when a control measure is both available and fully functional, indicating optimal compliance and effectiveness. A score of 0.5 is assigned when the control measure exists but is not currently operational, highlighting a partial implementation that may still pose a risk.

If the control measure is not yet available but is in the process of being procured or implemented, it receives a score of 0.25, signifying intention and planning without current functionality. The lowest score, 0, is reserved for situations where no reliable information is available; this includes cases where the measure is entirely absent, the data is faulty, or the information provided is irrelevant. The corresponding codes and abbreviations, Y for "Yes," NOP for "Not Operational," P for "Proposed," and NA/FD/DI for "Not Available," "Faulty Data," or "Data Irrelevant," serve as standardised indicators for quick reference and consistent reporting.

Availability of Measures	Code & their abbreviations	Scoring factor
Control measures are available and functioning properly	Yes (Y)	1
Control measures are available but not operational	Not Operational (NOP)	0.5
Control measure is not available, but its procurement is in process	Proposed (P)	0.25
Lack of information: The Measure is not available at all, or Faulty data is reported, or Irrelevant data is reported	Not Available (NA)/ Faulty Data (FD)/ Data Irrelevant (DI)	0

Table 5: Allocation of scoring factor for the assessment of dust control-related measures adopted by the coal mines.

Site location	Category of Mine	Abbreviations
Moonidih colliery	Underground Mine	U1
Gopalichuck OCP	Open Cast Mine	O1
Baghmara	Mixed Type	M1
Damoda Colliery	Open Cast Mine	O2
Gondudih Kusunda colliery	Open Cast Mine	O3
Amalgamated Keshalpur West Munidih colliery	Mixed Type	M2
E. J Area colliery	Mixed Type	M3
Dahibari Basantimata colliery	Open Cast Mine	O4

Table 6: Categorization of the selected coalmines as per the mining method for field visit and site abbreviations.

The table (Table 7) below presents the observations recorded for each of the eight mining sites, based on various mitigation measures implemented to control dust and pollution.

Mitigation Methods	Weightage	U1	O1	M1	O2	O3	M2	M3	O4
CAAQMS	0.1	NOP	NOP	P	NA	P	NA	P	NA
PM10 ANALYSER	0.1	FD	Y	Y	Y	Y	Y	Y	NA
Green belt	0.1	DI	NA	Y	NA	Y	NA	Y	NA
Road side plantation	0.1	NA	Y	Y	NA	Y	Y	Y	NA
Water sprinklers /tankers	0.1	Y	Y	Y	Y	Y	Y	Y	Y
Fog cannon	0.1	Y	Y	Y	Y	Y	NOP	Y	Y
Coal handling plant	0.1	NA	NA	NA	NA	Y	NA	NA	NA
Wet drilling	0.1	Y	Y	Y	Y	Y	Y	Y	NA
Wheel washing	0.1	P	NOP	Y	NA	NA	NA	NA	NA
OB dump management	0.1	NA	Y	Y	NA	Y	NA	Y	Y

Table 7: Observations recorded for each of the eight mining sites, based on various mitigation measures implemented to control dust and pollution.

The detailed observations made across all eight mining sites regarding dust management are as follows:

Fogging canon

A fogging cannon is used in mining to control dust by spraying a fine mist of water droplets that bind with dust particles, causing them to settle quickly. Fogging cannons are mobile and can be directed to key areas like crushers and conveyors.
During the site visits, it was observed that all mines, except Amalgamated Keshalpur, use fogging cannons, which have shown positive impacts on dust management and reduction.

During the site visits, it was observed that all mines, except Amalgamated Keshalpur, use fogging cannons, which have shown positive impacts on dust management and reduction.

Figure 5: Fog cannons at different mines.

Water Sprinklers

Water sprinklers are widely used in mining for dust control. They spray water over roads, stockpiles, and equipment, causing dust particles to settle, reducing airborne dust, and improving air quality. Sprinklers can be stationary or mobile, placed along traffic routes to control dust from vehicles and equipment. This also helps reduce wear on machinery by minimizing dust accumulation.

In the study, it was observed that, except for Dahibari Basantimata, all the mines included in the study have water sprinklers for dust management, effectively helping to control dust levels by spraying water over key areas such as roads, stockpiles, and equipment.

Figure 6: Water sprinklers at different mines.

Wet Drilling

Wet drilling is an effective dust control method, particularly in open-pit mining or quarry operations. Wet drilling mitigates airborne dust by directly applying water to the drilling site, thereby reducing the amount of dust released into the air.

The wet drilling technique is implemented at Damoda Colliery, Moonidih Colliery, and Gopalichuck OCP.

Use of Water in Crushers

Crushers play a vital role in coal mining operations, as they help break down large pieces of mined coal into smaller, more manageable sizes for further processing or use. During site visits, it has been observed that applying water in crushers effectively helps control particulate matter (PM) levels. Additionally, using water in crushers reduces the potential for dust generation during the transportation of pulverised coal via conveyors, as the coal remains in a wet state when it is dropped onto the stockpile.

Figure 7: Water sprinklers at crusher feeding point.

Coal Handling Plant

A Coal Handling Plant (CHP) is a critical facility in mining operations that manages the transportation, storage, and processing of coal, ensuring efficient handling and reducing dust emissions during coal transfer and storage. The use of curtains around the crusher plant helps in capturing the dust which would otherwise go airborne, or get settled on vegetation and get frequently resuspended. In underground mines, pulverised coal is transported to the surface via conveyors and stored in large stockpiles before being sent to consumers based on demand. If left unprotected from the wind, the coal in these stockpiles can become resuspended. To prevent this, protective walls should be built around the conveyors and stockpiles. These walls must be porous to avoid direct wind impact, which could affect the structural stability, and to prevent the creation of negative pressure behind the wall.

None of the mines assessed in the study have a Coal Handling Plant (CHP) installed.

Figure 8: Curtains; Vegetation covered with coal dust around the crushers plant.

Figure 9: Site Porous walls around the conveyor and stockpile.

Surface Stabilisation

Paving haul and other mine roads can significantly reduce dust resuspension. Properly maintained, high-strength paved roads help minimize the spillage of coal and overburden during transportation. Spilled coal and overburden, when subjected to the movement of heavy equipment and haul trucks, become pulverized, leading to the generation of airborne fine particles

Figure 10: Haul truck; Destabilised haul road.

Covered Transportation of Coal and OB

Coal and overburden (OB) often generate a significant amount of dust during transportation. Effective overburden (OB) dump management is essential to prevent dust generation, enhance stability, and minimize environmental impacts, which includes proper compaction, stabilization, and vegetation of OB dumps to reduce erosion and dust resuspension and Covered transportation helps contain this dust, preventing it from dispersing into the air. Additionally, it minimises spillage, preventing the materials from being pulverised and becoming airborne.

Gondudih Kusunda Colliery, E.J Area Colliery, Dahibari Basantimata, and Gopalichuck OCP are effectively managing their overburden (OB) dumps, while the remaining mines lack any OB dump management practices.

Figure 11: Partially covered transportation of coal.

Green Belts

A green belt in coal mines is essential for dust management, acting as a natural barrier that helps prevent the dispersion of dust particles into the air, thereby improving air quality around the mining area.

None of the mining sites included in the study have established a green belt effectively, with the exception of Moonidih Colliery, which has shared data regarding its development, though this information is not relevant.

Road Plantation

Road plantation is essential for dust management in mining areas as it helps to reduce the resuspension of dust particles caused by vehicular movement. The vegetation acts as a natural barrier, trapping dust and improving air quality by preventing dust from becoming airborne, particularly along frequently used haul roads.

None of the eight mines under study - Baghmara, Damoda Colliery, Gondudih Kusunda Colliery, Amalgamated Keshalpur, E.J Area Colliery, Dahibari Basantimata, Gopalichuck OCP, and Moonidih Colliery - have implemented road plantation for dust management.

Wheel washing systems

Wheel washing systems are essential for minimizing the spread of dust and debris from mining vehicles, ensuring that dirt and particulate matter are removed from vehicle tires before they exit the mining site.

Moonidih Colliery has proposed a wheel washing system, while the other mines under study do not have any such system in place, nor have they shared any plans for its implementation.

In addition to scores, weightage is assigned to each mitigation measure to reflect its relative importance, with more effective measures receiving higher weightage. The scores are then multiplied by their corresponding weightage. The final scores allow for a comparison of performance across different mines. This enables mines to assess the relative effectiveness of various mitigation measures, helping them identify areas for improvement and take appropriate action.

Composite scores from different mines can be compared to identify the most effective mitigation measures, which can then be recommended to other mines for implementation. This approach provides a quantitative method to pinpoint best practices in dust mitigation. When the final scores are compared, it highlights that mines with higher scores are more effective at controlling dust, while mines with lower scores are less successful in reducing dust from their various activities.

Mitigation Methods	Weightage	U1	O1	M1	O2	O3	M2	M3	O4
CAAQMS	0.1	0.05	0.05	0.025	0	0.025	0	0.025	0
PM 10 ANALYSER	0.1	0	0.1	0.1	0.1	0.1	0.1	0.1	0
Green belt	0.1	0	0	0.1	0	0.1	0	0.1	0
Road Side plantation	0.1	0	0.1	0.1	0	0.1	0.1	0.1	0
Water sprinklers/tankers	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Fog cannon	0.1	0.1	0.1	0.1	0.1	0.1	0.05	0.1	0.1
Coal handling plant	0.1	0	0	0	0	0.1	0	0	0
Wet drilling	0.1	0.1	0.1	0.1	0.1	0.1	0	0.1	0
Wheel washing	0.1	0.025	0.05	0.1	0	0	0.1	0	0
OB dump management	0.1	0	0.1	0.1	0	0.1	0	0.1	0.1
Composite Score		**0.375**	**0.7**	**0.825**	**0.4**	**0.825**	**0.45**	**0.725**	**0.3**

Table 8: Scoring for each of the eight mining sites, based on various mitigation measures implemented to control dust and pollution.

An analysis of the composite scores for dust mitigation practices across the eight selected coal mines reveals considerable variability in implementation and compliance levels. The highest composite scored (0.825) Baghmara mines and Gondudih Kusunda colliery scored, followed by E.J colliery & Gopalichak OCP (0.725 & 0.7 respectively) recorded reflecting relatively better adoption of dust suppression measures such as water sprinkling, fog cannons, PM10 analysers, wet drilling, wheel washing, and overburden (OB) dump management. Amalgamated Keshalpur (0.45), Damoda Colliery (0.4) and Moonidih Colliery (0.375) also showed moderate levels of compliance, though notable gaps remain in key areas like green belt development, and coal handling infrastructure.

In contrast Dahibari Basantimata scored significantly lower (both 0.3), indicating a lack of basic dust mitigation infrastructure and practices. Commonly missing measures across these lower-performing sites included the absence of CAAQMS, green belts, roadside plantations.

Coal Mines	Score out of 1	Potential Areas for Improvement
Moonidih Colliery	0.375	PM 10 ANALYSER, Green belt, Road side plantation, OB dump management, Coal handling plant
Gopalichuck OCP	0.7	Green belt, Coal handling plant, Wheel washing
Baghmara	0.825	CAAQMS(Proposed), Coal handling plant,
Damoda Colliery	0.4	CAAQMS, Green belt, Road side plantation, Coal handling plant, Wheel washing, OB dump management
Gondudih Kusunda Colliery	0.825	CAAQMS(Proposed), Wheel washing
Amalgamated Keshalpur	0.45	CAAQMS, Green belt, Coal handling plant, Wheel washing, OB dump management
E.J Area Colliery	0.725	CAAQMS(Proposed), Coal handling plant, Wheel washing,
Dahibari Basantimata	0.30	CAAQMS, Green belt, Road side plantation, Coal handling plant, Wet drilling, Wheel washing, PM 10 ANALYSER

Table 9: Potential area for improvement on the basis of scoring.

Interpretation

The following Interpretations were made regarding dust mitigation and environmental management at the mines:

1. Fog cannons and water sprinklers have proven to be the most effective methods for controlling immediate dust emissions from various coal handling processes. These measures are functional in nearly all mines, with the exception of the E.J. Colliery.

2. A significant number of vehicles are used for various mining activities, and their emissions remain airborne for extended periods. Therefore, it is recommended that all mines implement proper monitoring systems for vehicular emissions.

3. It is recommended that coal processing be conducted in an enclosed environment to better control dust emissions. The Coal Handling Plant (CHP) is identified as a major source of dust, particularly due to activities like loading, unloading, and size reduction. Crushers, in particular, generate significant amounts of dust, as evidenced by the high PM levels observed near these areas during site visits. Workers operating in these zones are consistently exposed to harmful PM concentrations, which can lead to respiratory diseases after prolonged exposure.

4. A significant number of vehicles are used for various mining activities, and their emissions remain airborne for extended periods. Therefore, it is recommended that all mines implement proper monitoring systems for vehicular emissions.

5. A noticeable gap exists in the areas of green belt development and roadside plantation. There is a need for comprehensive planning to increase the extent of plantation coverage and improve the survival rate of planted vegetation.

6. Heavy vehicles exiting the mines are found to carry dust onto public roads, contributing to increased airborne dust concentrations in residential areas. There is a need for a functional wheel washing system at the mine exit points to prevent this issue, as such systems are either non-functional or entirely absent in most mines.

These observations indicate critical areas for improvement in dust control and environmental management within the mines.

3.1.2. OBSERVATIONS FOR COAL DISTRIBUTION AND ITS MODE OF TRANSPORTATION

In coal mining, dust is not only generated during excavation and processing but also significantly during the transportation of coal. Coal is distributed to various consumers, including power plants, coal washeries, other dependent industries (such as local vendors), and additional sectors. The transportation of coal occurs through different modes, including railways, roads, conveyor belts and others. Among these, conveyors are the most effective in controlling dust; however, their use is limited to shorter distances. For long-distance transportation, railways emerge as the most efficient mode.

The study also seeks to understand the coal production and transportation processes in the mines under review, specifically focusing on how these activities contribute to dust emissions and air quality. The mode of coal distribution has also been assessed across different sectors.

The table below details the production capacity and other relevant characteristics of each of the coal mines under study.

Name of Mine	Production Capacity (TPD)	EC Capacity (TPD)	Stripping Ratio	Distance from Dhanbad City
Moonidih Colliery	1388.89	8219.18	NA	10km
Gopalichuck OCP	1200-1500	978.08	1:17	8.6km
Baghmara (Cluster III) (Mixed type)	2674.8	NA	NA	16.6km
Damoda Colliery	7844.74	13698.63	1:5-7	33.8km
Gondudih Kusunda Colliery	4616.43	8219.17	1:3.57	7.5km
Amalgamated Keshalpur West Mudidih Colliery	10411	26614.38	1:2.5	14km
E. J Area Colliery	3060.2	2739.72	1:5-6	8.7km
Dahibari Basantimata Colliery	1712.32	NA	NA	46.3km

Table.10: Production capacity and EC capacity of different mines (in Tonne Per Day i.e. TPD).

The stripping ratio is a key metric used in mining, particularly in open-pit mining, to measure the amount of waste material (often called overburden) that must be removed to extract a given amount of ore or coal. It is calculated by dividing the volume of overburden removed by the volume of ore extracted.

Name of Mine	EC Capacity (TPD)	Production Capacity (TPD)	Transportation by Road	Transportation by Railways	Transportation by Conveyor Belt
Moonidih Colliery	8219.18	1388.89	182.2	-------------	1206.66
Gopalichuck OCP	978.08	1200-1500 (Average-1350)	912.18	-------------	-----------
Baghmara (Cluster III)	NA	2674.8	401.2	2273.58	-----------
Damoda Colliery	13698.63	7844.74	Data not provided	Data not provided	Data not provided
Gondudih Kusunda Colliery	8219.17	4616.43	2400.55	2215.88	------------
Amalgamated Keshalpur West Mudidih Colliery	26614.38	10411	1568.98	6275.8	------------
E. J Area Colliery	2739.72	3060.2	Data not provided	Data not provided	Data not provided
Dahibari Basantimata Colliery	NA	1712.32	Data not provided	Data not provided	Data not provided
Total coal production of 8 mines	**60469.16**	**33058.38**	**5465.11**	**10765.26**	**1206.66**
Production capacity (TPD) for the mines which provided the transportation mode data	**44030.81**	**20441.12(61.83 % of the total production capacity)**	**5465.11**	**10765.26**	**1206.66**
Percentage distribution of different mode of transportation			**26.73%**	**52.66%**	**5.90%**

Table.11: Production capacity and EC capacity of different mines for different mode of transportation (in Tonne Per Day i.e. TPD)[AJ1].

The distribution of coal from each mining unit to various sectors - such as washing plants, power plants, local vendors, and others—has also been evaluated and is presented below.

Coal Distribution	Route	Damoda Colliery	Baghmara	Gondudih Kusunda Colliery	Amalgamated Keshalpur	E.J Area Colliery	Dahibari Basantimata	Gopalichuck OCP	Moonidih Colliery
Washery	Road	NA	-	-	392.24	NA	NA	843.79	182.22
	Railway	NA	-	-	-	NA	NA	-	-
	Conveyors	NA	-	-	-	NA	NA	-	1206.66
	Other	NA	-	-	-	NA	NA	-	-
Powerplant	Road	NA	-	1477.26	392.24	NA	NA	68.39	-
	Railway	NA	2273.58	2215.88	6275.8	NA	NA	-	-
	Conveyors	NA	-	-	-	NA	NA	-	-
	Other	NA	-	-	-	NA	NA	-	-
Local Vendor	Road	NA	401.22	-	784.5	NA	NA	-	-
	Railway	NA	-	-	-	NA	NA	-	-
	Conveyors	NA	-	-	-	NA	NA	-	-
	Other	NA	-	-	-	NA	NA	-	-
Any Other	Road	NA	-	923.29	-	NA	NA	-	-
	Railway	NA	-	-	-	NA	NA	-	-
	Conveyors	NA	-	-	-	NA	NA	-	-
	Other	NA	-	-	-	NA	NA	-	-
Total Production (TPD)			**2674.8**	**4616.43**	**7844.74**			**910.34**	**1388.88**

Table 12: Coal distribution for various mines (in Tonne Per Day i.e. TPD).

Coal Distribution	Route	Damoda Colliery	Baghmara	Gondudih Kusunda Colliery	Amalgamated Keshalpur	E.J Area Colliery	Dahibari Basantimata	Gopalichuck OCP	Moonidih Colliery
Washery	Road	NA	-	-	5%	NA	NA	92.69%	13.11%
	Railway	NA	-	-	-	NA	NA	-	-
	Conveyors	NA	-	-	-	NA	NA	-	86.88%
	Other	NA	-	-	-	NA	NA	-	-
Powerplant	Road	NA	-	32%	5%	NA	NA	7.30%	-
	Railway	NA	85%	48%	80%	NA	NA	-	-
	Conveyors	NA	-	-	-	NA	NA	-	-
	Other	NA	-	-	-	NA	NA	-	-
Local Vendor	Road	NA	15%	-	10%	NA	NA	-	-
	Railway	NA	-	-	-	NA	NA	-	-
	Conveyors	NA	-	-	-	NA	NA	-	-
	Other	NA	-	-	-	NA	NA	-	-
Any Other	Road	NA	-	20%	-	NA	NA	-	-
	Railway	NA	-	-	-	NA	NA	-	-
	Conveyors	NA	-	-	-	NA	NA	-	-
	Other	NA	-	-	-	NA	NA	-	-
Total Production (TPD)			**100%**	**100%**	**100%**			**100%**	**100%**

Table.13: Coal Percentage distribution for various mines (in Tonne Per Day i.e. TPD).

Interpretation

Coal transportation from mining units is a significant contributor to particulate matter (PM) pollution. The coal supplied to allied industries and local vendors plays a substantial role in elevating PM in the surrounding areas. Numerous coal-dependent industries operate in proximity to mining sites, often without adequate monitoring, and contribute extensively to dust pollution.

The observations have been made and presented for all sectors where coal is being transported, including the modes of transportation used.The key findings are as follows:

1. Road transport is the primary mode of coal distribution, serving various destinations, including washery, power plants, local vendors, and other purposes.

2. Conveyors are primarily used in washery distribution at Moonidih colliery (86.88%).

3. Railway Transport plays a dominant role in supplying power plants, particularly from Baghmara (85%), Gondudih Kusunda (48%), and Amalgamated Keshalpur (80%).

The classification of transportation modes across various sectors has been conducted to provide a detailed understanding of the coal distribution system. This approach allows for a more thorough analysis of the transportation methods, their efficiency, and their environmental impact, enabling better strategies for mitigation and improvement in the coal supply chain.

The table below outlines the mode-wise coal transportation to various sectors from the mines under study.

Sector	Mine	Mode of Transport	Percentage
Washery Distribution	Gopalichuck OCP	Road	92.69%
	Moonidih Colliery	Road	13.11%
	Moonidih Colliery	Conveyor	86.88%
Power Plant Distribution	Gondudih Kusunda	Road	32%
	Gondudih Kusunda	Railway	48%
	Amalgamated Keshalpur	Railway	80%
	Baghmara	Railway	85%
Local Vendor Supply	Baghmara	Road	15%
	Amalgamated Keshalpur	Road	10%
Other Consumers	Gondudih Kusunda	Road	20%

Table 14: Transportation mode across Various sectors.

For washery distribution, Gopalichuck OCP supplies the highest amount of coal via road, whereas Moonidih Colliery utilizes both road and conveyor systems for transportation. In terms of power plant distribution, Gondudih Kusunda employs a balanced supply chain, using both road and railway modes. Meanwhile, Amalgamated Keshalpur and Baghmara emerge as major suppliers via railway, contributing around 80% and 85% respectively.

For local vendor supply, Baghmara is the only mine supplying 15% of its production to local vendors via road, while Amalgamated Keshalpur provides 10% through the same mode. Additionally, Gondudih Kusunda distributes 20% of its production via road to other consumers, highlighting the significance of road transport across various end-use sectors.

Further, the coal distribution data reveals varied patterns across the five mines. Baghmara and Gondudih Kusunda primarily supply coal to power plants (85% and 80% respectively), with the remainder going to local vendors. Amalgamated Keshalpur also focuses on power plants (85%), while supplying small portions to local vendors (10%) and washeries (5%). Gopalichuck OCP and Moonidih Colliery are predominantly washery-focused, with 92.6% and 100% of their coal going to washeries, respectively. Data for Damoda Colliery, E.J Area Colliery, and Dahibari Basantimata is not available.

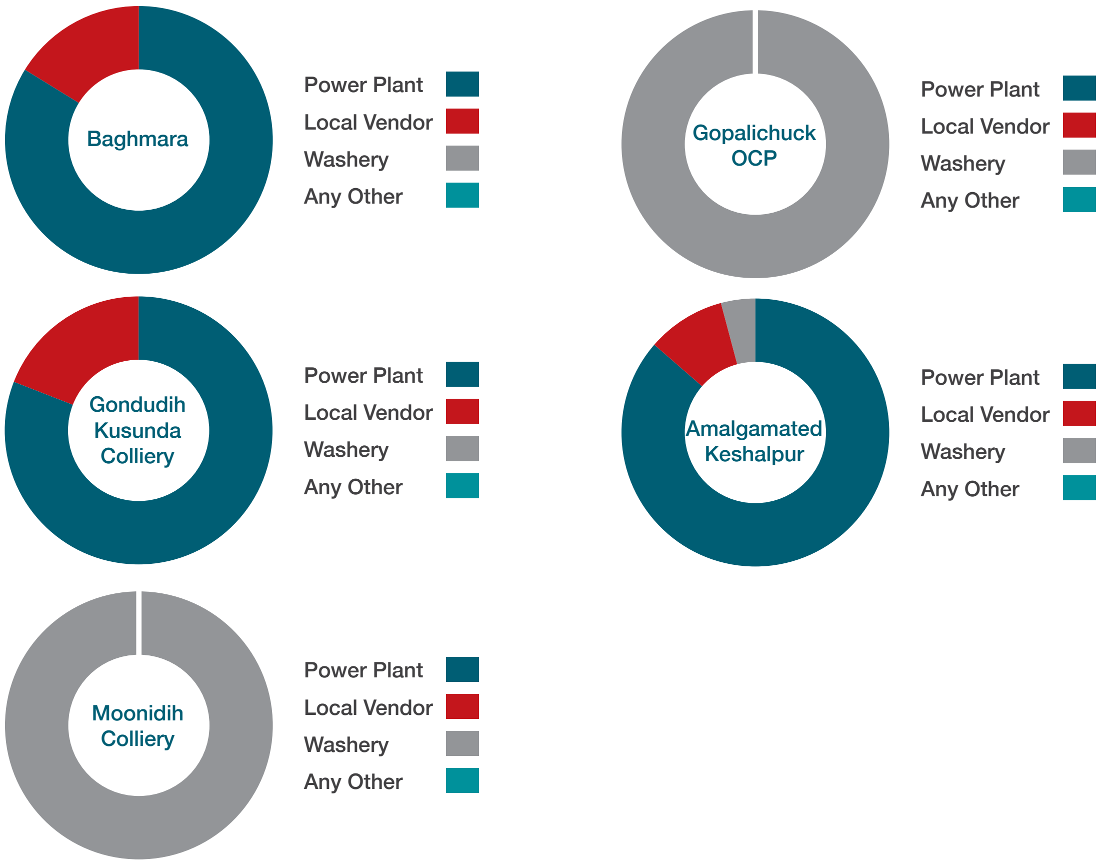


Figure 12: Sector-wise Distribution of Coal from Selected Mines

Analysing coal distribution and transportation methods has highlighted the need for a dedicated study focusing specifically on the supply chain.

It is generally observed that an increase in coal production correlates with a rise in PM_{10} emissions and concentrations, as higher production typically involves greater excavation activity and increased fossil fuel consumption. However, the extent of emissions is also influenced by factors such as the production technology used and the effectiveness of dust mitigation measures implemented.The study also attempts to compare average PM_{10} values with production data to better understand this trend and assess the relationship between output and emission control efficacy.

This is evident from the data, which shows that even with higher production levels (greater than 3500 TPD), the average mitigation score is comparatively better (0.3088) than that of mines with lower production capacities (1500 to 3500 TPD), which have a lower average score of 0.158.. However, a more detailed examination is essential to better understand their environmental impact and implement effective mitigation measures.

Name of Mine	PM10	Score out of 1	Production Capacity (in TPD)
Baghmara (Cluster III) (Mixed type)	126	0.83	2674.8
Damoda Colliery	264.06	0.40	7844.74
Gondudih Kusunda Colliery	348.7	0.83	4616.43
Amalgamated Keshalpur West Mudidih Colliery	2718.49	0.45	10411
E. J Area Colliery	131.95	0.73	3060.2
Dahibari Basantimata Colliery	194.49	0.30	1712.32
Gopalichuck OCP	NA	0.70	1200-1500
Moonidih Colliery	NA	0.38	1388.89

Table 15: Comparison between average PM 10 values, Its score and Production Capacity (TPD).

Coal production group (in TPD)	List of Mines	Average score
Less than 1500	Moonidih Colliery, Gopalichuck OCP	0.54
Greater than 1500 & less than 3500	Dahibari Basantimata Colliery, E. J Area Colliery, Baghmara (Cluster III)	0.62
Greater than 3500	Amalgamated Keshalpur West Mudidih Colliery, Gondudih Kusunda Colliery, Damoda Colliery	0.56

Table 16: Comparison between Average score and different range of coal production (in Tonne per day).

3.1.3 REAL TIME MEASUREMENT OF PM

Using real-time PM measurements, the study aims to identify the specific mining activities that contribute most to PM emissions and evaluate the effectiveness of current dust control measures.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Siding locations	1 minute	119.87	75.57
Haul road	1 minute	153.90	80.23
In the Garden	1 minute	104.23	73.90

Table 17: Activity wise measured PM (µg-m-3) using the GRIMM at the Baghmara coal mines.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Excavation point	1 minute	264.06	77.20

Table 18: Activity wise measured PM (µg-m-3) using the GRIMM at the Damoda Colliery coal mines.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Excavation point	1 minute	348.70	160.48

Table 19: Activity wise measured PM(µg-m-3) using the GRIMM at the Gondudih Kusunda Colliery coal mines.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Crusher point	1 minute	3123.60	742.56
Haul Road	1 minute	494.50	220.90

Table 20: Activity wise measured PM(µg-m-3) using the GRIMM at the Amalgamated Keshalpur West Munidih colliery.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
OB Dump Excavation point	1 minute	131.95	67.50

Table 21: Activity wise measured PM(µg-m-3) using the GRIMM at the E.J Area Colliery coal.

Activity	Sampling time	PM_{10}	$PM_{2.5}$
Coal washery	1 minute	205.82	81.52
OB dump reclamation site	1 minute	183.16	78.98

Table 22: Activity wise measured PM(µg-m-3) using the GRIMM at the Dahibari Basantimata.

Name of mine	Average PM_{10}	Average $PM_{2.5}$	$\left\{\frac{\text{Average PM2.5}}{\text{Averge PM 10}}\right\}$ Ratio
Baghmara (Cluster III)	126	76.56	0.61
Damoda Colliery	264.06	77.2	0.29
Gondudih Kusunda colliery	348.7	160.48	0.46
Amalgamated Keshalpur West Mudidih colliery	2718.49	609.97	0.23
E. J Area colliery	131.95	67.5	0.51
Dahibari Basantimata colliery	194.49	80.25	0.41

Table 23: Average PM concentrations in different mines.

Interpretation

The concentration of particulate matter (PM) varies across different mining operations, with the highest PM levels recorded at the crusher point. A significant spike in PM concentration is noted immediately when coal is fed into the crusher, indicating a rapid generation of dust. To mitigate this, dust suppression measures such as continuous water sprinkling during the unloading process and the use of a curtain (isolation) around the crusher plant have proven effective in controlling the spread of dust in the surrounding environment. Additionally, PM concentration is influenced by activities such as blasting and the movement of heavy machinery. Both blasting and the operation of heavy equipment result in temporary increases in PM levels. Dust generated from the movement of heavy earth-moving machinery (HEMMs) can be managed through regular water sprinkling and reinforcing haul roads.

3.2 DETAILED OBSERVATIONS

A total of eight mines in the study were taken to assess the air pollution caused by mining activities and to identify sustainable mining practices. Detailed observations and interpretations are presented below:

3.2.1 MINE-TYPE WISE

3.2.1.1 OPEN CAST MINE

3.2.1.1 (a) GOPALICHUCK OCP

Gopalichuck OCP is an opencast mine situated in the north eastern part of Jharia coalfield, District Dhanbad, Jharkhand. The area lies between latitudes 23° 42' 13" north to 23° 42' 49" north and longitude 86° 25' 29" east to 86° 26' 06" east. The total mine area is 241.94 ha as per the EC.

During the site visit of Gopalichuck OCP, the following key observations were found:

- **Stripping Ratio:** 1:17 (tonne of overburden (OB) to cubic meters of coal).
- **Fuel Consumption for Explosives:** 5.493 kg/tonne, with 0.2371 detonators per tonne.
- **Drilling Operations:** Wet operated drills are used.
- **Coal Handling:** No Coal Handling Plant (CHP); coal is transported to Tata Washery (receiving end).
- **Ambient Air Monitoring:** Manual monitoring conducted monthly by CMPDI, with half-yearly testing for heavy metals.
- **Air Quality Monitoring:** Two PM10 analysers are functional, but the Continuous Ambient Air Quality Monitoring System (CAAQMS) is non-operational.
- **Wheel Washing System:** Non-operational; no active wheel washing in place.
- **Dust Control Measures:** Water sprinkling is done six times daily (three times per shift) using four 12,000-liter capacity sprinklers, covering approximately 30 km.
- **Additional Dust Mitigation:** One fog cannon in use.
- **Proposed Measures:** A mechanical sweeping tender is under proposal.
- **HEMMs:** Heavy Earth Moving Machines (HEMMs) are outsourced for operations.

Recommendations

To effectively reduce coal spillage and minimize the resuspension of dust during the transportation process, it is recommended that the roads be paved to ensure smoother and more controlled movement of vehicles. Additionally, the induction of a mechanical sweeper for regular and thorough cleaning of the transport routes will help to maintain cleaner road surfaces and further prevent the dispersion of coal particles into the surrounding environment.

Figure 13: Site photographs of main mine site, & fogging cannon at Gopalichuck OCP

3.2.1.1 (b) DAMODA COLLIERY

Damoda colliery is an opencast mine, situated near Barora area, Sijua, Bokaro Steel City, Jharkhand. The area lies between latitudes 23.76027 N to 23.684722 N, longitude 86.15027 E to 86.18694 E The total mine area is 575 ha as per the EC.

During the site visit of Damoda Colliery, the following key observations were found:

- It was observed that coal is entirely transported via road to a nearby washery located 5–6 km away, with a capacity of 5 MTPA.
- The stripping ratio is between 1:5–7 (tonne/m³).
- There has been a shift from 70 outsourced vehicles (until July 2024) to 2–3 departmental vehicles, due to reduced production arising from land-related constraints (current output: 800–900 TPD).
- Dust control measures include 2 operational water sprinklers, 5 fog cannons proposed, and 1 additional sprinkler proposed at the coal dump site.
- One PM10 analyser is operational; however, CAAQMS is absent. Air quality monitoring is done fortnightly by CMPDI using manual methods.
- The drilling machine is equipped with a dust collector and water sprinkler.
- The crusher has a bucket capacity of 2.5–3.5 tonnes, and the maximum permissible load at the weighbridge is 36 tonnes.
- Workers are provided with safety kits.

Figure 14: Site photographs of fogging cannon; haul truck, the audit team; GRIMM device while in operation at Damoda Colliery.

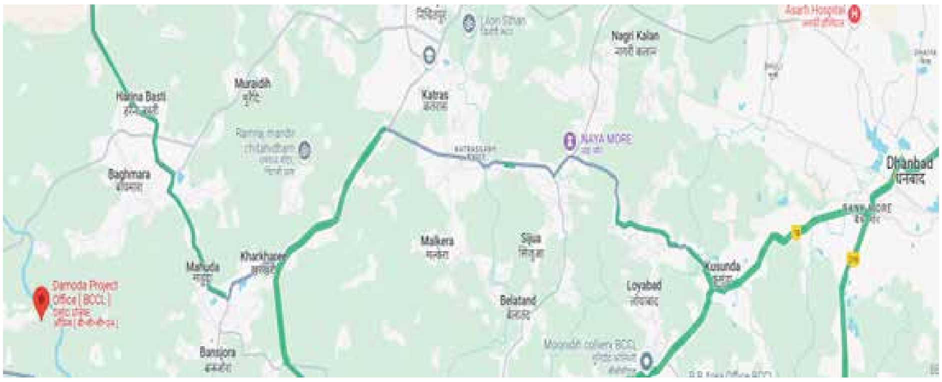


Figure 15: Map depicting routes for Dhanbad to Damoda Mines.

3.2.1.1 (c) GONDUDIH KUSUNDA COLLIERY

Gondudih Kusunda colliery is an opencast mine, situated 6 km from Dhanbad Railway Station Westwards. Ekra Jore flow in the north south direction of west side of property. The area lies between latitudes N23°47'26" & longitude E86°23'13". The total mine area is 471 ha as per the EC.

- During the site visit of Gondudih Kusunda Colliery, two of the five open-cast mines in the cluster—ENA and Amalgamated Colliery—were inspected. ENA was noted to have the highest production capacity at 3 MTPA (30 lakh tonnes per annum).
- Coal from ENA is transported via road to Sindhri, and thereafter by rail to Maithan Power Station.
- Smaller pulverised overburden (OB) is separated to prevent wind erosion and is utilised for strengthening unpaved internal roads.
- Burnt coal dust resulting from underground mine fires is suppressed using water, supplied through pipelines, with additional support from fog cannons and fire brigades.
- The OB dump has reached a height of 83 meters, within the permissible limit of 120 meters, and a width of 30 meters.
- Loaded vehicles operate at speeds between 15–20 km/h, while unloaded vehicles move at 20–50 km/h.
- The stripping ratio stands at 1:357 (tonnes of OB per m^3 of coal).
- In the pulverisation plant, coal is fed wet to control dust resuspension, achieving a final particle size of 0.01 mm.

Figure 16: Site photographs of crusher unit; OB dump; water sprinkler while in operation & Dozer at Gondudih Kusunda colliery.

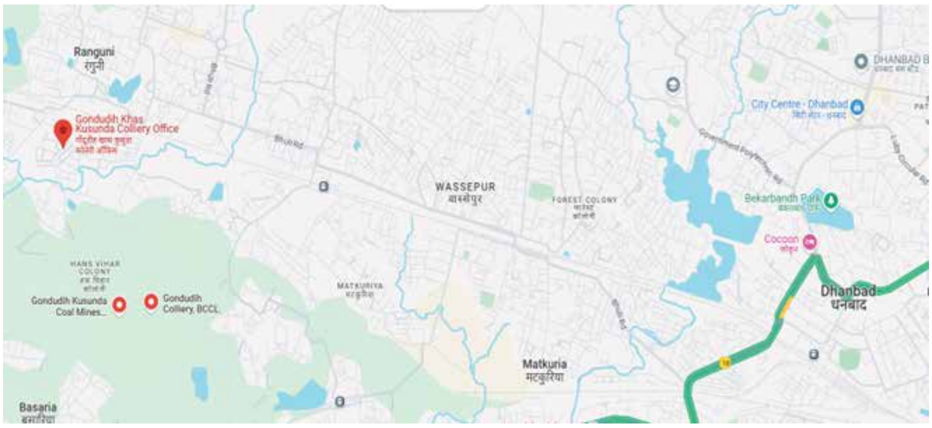


Figure 17. Map depicting routes for Dhanbad to Gondudih Kusunda colliery.

3.2.1.1 (d) DAHIBARI BASANTIMATA COLLIERY

During the site visit of Dahibari Basantimata, the following key observations were made:

- During the joint inspection of Dahibari Basantimata Colliery, it was observed that coal is transported in a 60:40 rail-to-road ratio.
- The site hosts one crusher, with an additional crusher located at the washery.
- The mine comprises an open-cast unit with a capacity of 1.693 MTPA and an underground unit with a capacity of 0.273 MTPA.
- A proposed water harvesting plant is expected to be commissioned before the pre-monsoon season.
- Over the past five years, 57 hectares of green belt have been developed around the site.
- There are seven overburden (OB) dumps, of which two are currently active.
- A toe wall has been constructed near the Khudia River to prevent soil and sediment runoff.
- One truck-mounted fog cannon is operational for dust suppression.
- Current production is approximately 5 lakh tonnes, against the Environmental Clearance (EC) capacity of 17 lakh tonnes.
- The coal stockyard is located 3 km from the mining area.
- The mine primarily produces G-4/G-5 grade coal.
- Minimal dust emissions were observed from the silos containing washed coal, except during coal unloading operations.
- The coal is primarily dispatched to steel industries, power plants, and local vendors.

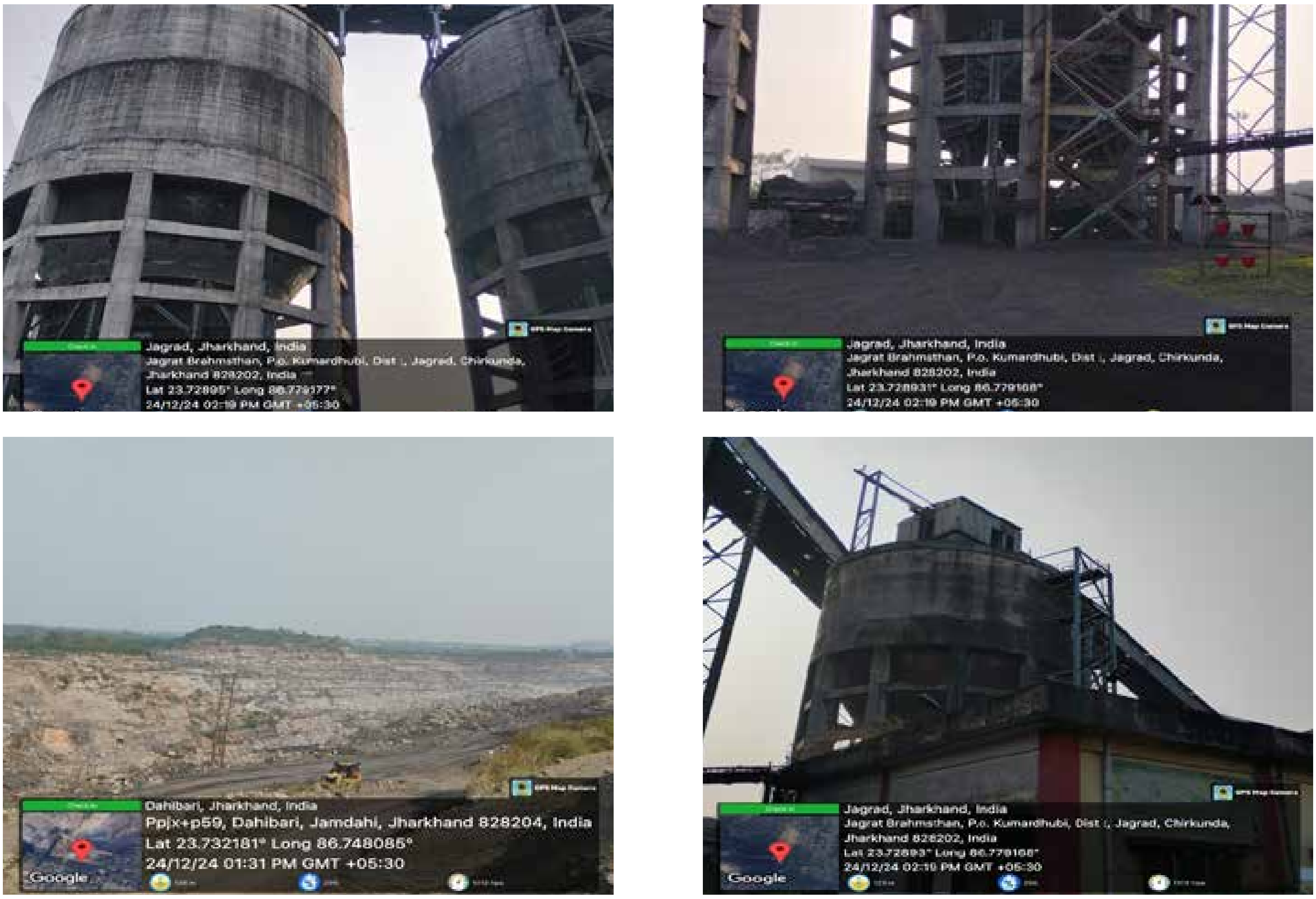


Figure 18: Site photographs of washery silos & Main Mine site at Dahibari Basantimata colliery.

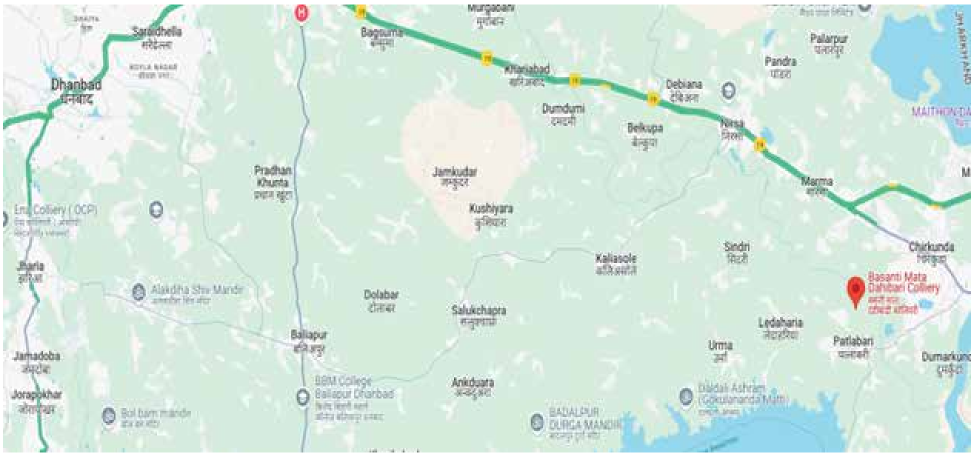


Figure 19: Map depicting routes for Dhanbad to Dahibari Basantimata colliery.

3.2.1.2 UNDERGROUND MINES

3.2.2.1 (a) MOONIDIH COLLIERY

Moonidih colliery mine located in W.J area is underground type having coordinates Latitude: 23°42′04″ and 23°45′42″ & Longitude 86°19′05″ and 86°22′26″ E with mine area of 1983 ha.

- During the joint inspection of Moonidih Colliery, it was noted that there are no washery rejects, as all coal products are sold directly.
- Coal production has consistently remained at 0.5 MTPA, with only one year of production data provided, despite a formal request for three years.
- The same figure of 0.5 MTPA is projected for future production as well.
- A 10 kilolitre capacity truck-mounted water sprinkler operates 2–3 trips daily, covering 5–10 km per trip, although no mileage data was provided.
- There is no Coal Handling Plant (CHP) at the site, and road transport is not used either for coal production or for transfer to the washery.
- One fog cannon is in use to suppress dust along the road connecting the mine to the Putki highway.
- A wheel washing system has been proposed, though it is yet to be implemented.
- A porous material covering has been recommended for the conveyor belt to control dust dispersion.
- The PM_{10} monitoring display was found to be faulty, displaying an unrealistically low value of 3 µg/m³, which raises concerns about its functionality and data reliability.

Recommendations

The conveyor, loading, and unloading systems should be covered with porous material to prevent low-pressure zones and resuspension of crushed coal, a wheel washing system should be installed, and spilled coal along the conveyor system should be frequently removed.

Figure 20: Site photographs of Covered conveyor system, PM10 Analyser, Stockpile and underground monitoring station of Gases at Moonidih Colliery.

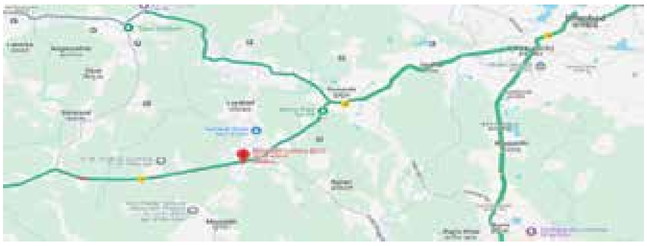


Figure 21: Map depicting routes for Dhanbad to Moonidih Colliery.

3.2.1.3 MIXED TYPE MINE

3.2.1.3 (a) BAGHMARA (CLUSTER III)

Baghmara is a mixed type mine, situated in the District Dhanbad, Jharkhand. The area lies between latitudes 23.7656° N & Longitude 86.2040° E. The total mine area is 1420.61 ha as per the EC.

The following observations were made. The site photographs are attached as Fig 10.

- It was observed that coal is transported by road to the siding, from where it is loaded into railway wagons.
- Covered coal transportation was verified at both the weighbridge and siding locations.
- Although a Continuous Ambient Air Quality Monitoring Station (CAAQMS) was mentioned in the questionnaire response (Google Form), no CAAQMS was found operational on-site. However, six PM_{10} analysers were functioning.
- Two mobile water sprinklers were found operational, though details of the vehicles were pending confirmation via email.
- The road leading to the siding was poorly constructed, contributing to dust dispersion.
- The wheel washing system was non-functional, with accumulated stagnant water observed at the site.
- Three trolley-mounted fog cannons (with a 100-meter range) and one truck-mounted fog cannon were operational for dust suppression.
- As part of personal protective equipment (PPE) distribution, 45 dust masks and 13 earplugs had been issued to employees.

Recommendations

To reduce dust resuspension and improve operational efficiency at Baghmara OCP, the connecting haul road to the siding should be strengthened for heavy loading to minimise spillage, wind barriers should be installed at the siding to control wind-blown pulverised coal dust generated by vehicle movement and nearby stockpiles, PPE kits and regular training should be enhanced to ensure only properly equipped workers are deployed, a rapid loading system with a conveyor belt and water sprinkling should be implemented for dust suppression, and the current stagnant pool-based wheel washing should be replaced with more effective methods.

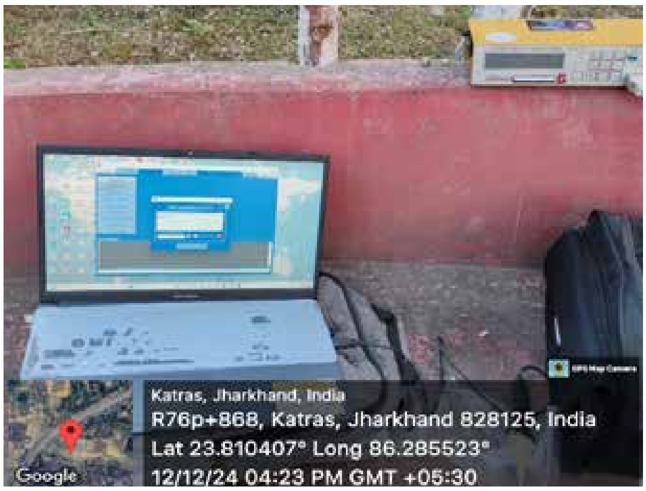


Figure 22: Site photographs of Audit Team, Siding Location, Stationary Fogging cannon & Railway wagon while loading of coal at Baghmara OCP.

3.2.1.3 (b) AMALGAMATED KESHALPUR WEST MUDIDIH COLLIERY

Amalgamated Keshalpur West Mudidih colliery is a mixed type mine, situated in the Village Keshalpur, PO Katrasgarh, Block Baghmara District Dhanbad, Jharkhand. The area lies between latitudes 23° 47’20” north to 23° 48’36” North and longitude 86° 18’ 55” east to 86° 19’ 44” East The total mine area is 325 ha as per the EC.

- At Amalgamated Keshalpur West Mudidih Colliery, it was observed that the mine operates with an Environmental Clearance (EC) capacity of 9.55 MTPA and a stripping ratio of 1:2.5.
- The site is equipped with four water tankers, each with a capacity of 25,000 litres, conducting 20 trips per day for dust suppression. It was noted that one full tanker load is consumed per 20 coal loading operations.
- One fog cannon was available on-site; however, it was under servicing during the inspection.
- The colliery operates three crushers, each producing coal with an approximate size of 10 cm.

- The Coal Handling Plant (CHP)/crusher area was identified as requiring additional dust suppression interventions.
- The market price of coal from this unit was reported to be approximately ₹10,000–₹11,000 per tonne.

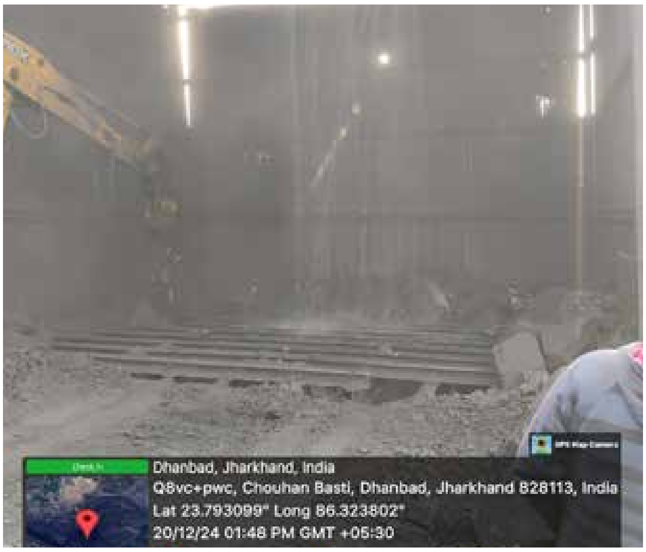


Figure 23: Site photographs of GRIMM device while on site data collection, Crusher conveyor, surrounding vegetation covered with coal dust, Crusher feeding system with water sprinkling at Amalgamated Keshalpur West Mudidih colliery.

Figure 24: Map depicting routes for Dhanbad to Keshalpur West Mudidih colliery.

3.2.1.3 E. J AREA COLLIERY

E.J Area colliery is a mixed type mine, situated in Bhowra, Dhanbad District, Jharkhand. The area lies between Latitude 23°41’30” to 23°40’00” North Longitude - 86°22’18” to 86°24’15” East. The total mine area is2057.47 ha as per the EC.

- At E.J Area Colliery, it was observed that the coal seam lies approximately 12 meters below ground level, with a stripping ratio ranging between 1:5 and 1:6.
- In situ coal is extracted through blasting, while the left portion of the mine has been backfilled.
- A 4000 GPM pump and an associated pipeline system are in operation to wet the backfilled material, aiding in dust suppression and slope stability.
- The colliery holds an Environmental Clearance (EC) capacity of 1 MTPA, while the current overburden removal activity is being carried out to support a production capacity of 2 MTPA.

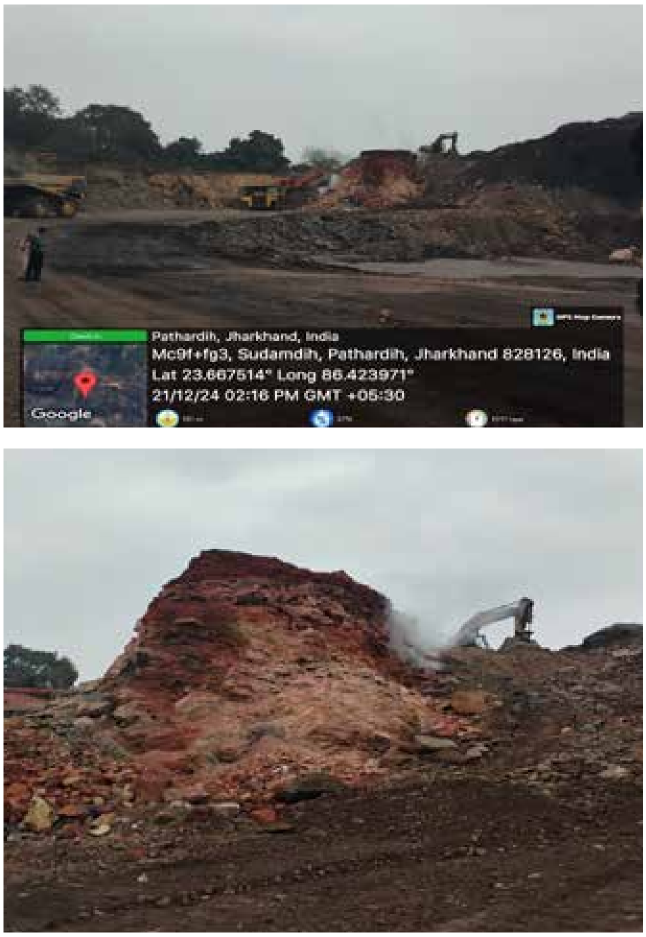


Figure 25: Site photographs of OB dump Excavation for relocation at E.J Area colliery.

4. GLOBAL EXAMPLES OF SUSTAINABLE PRACTICES

The efficacy of dust suppression tools, such as sprinklers and fogging cannons, has been extensively researched and established as highly effective in managing airborne dust. These technologies have demonstrated significant success in substantially reducing dust levels in mining environments, thereby minimizing the exposure of workers and the surrounding environment to harmful particulate matter. However, in light of global research findings, a range of advanced dust control practices have been implemented across mining operations worldwide. These practices have yielded notable improvements in air quality and have proven instrumental in mitigating dust-related health risks. Below are some of the prominent dust control measures that have been successfully integrated into mining operations globally.

1. Water Spraying Systems

- **Countries:** Australia, Canada, South Africa
- **Description:** One of the most common methods for controlling dust in mining operations is spraying water over roads, equipment, and stockpiles.
- **Sustainability Aspect:** To make this more sustainable, many mining companies use recycled water or implement closed-loop water systems to minimise water wastage.

2. Dust Suppressants

- **Countries:** United States, Brazil, Chile, Australia
- **Description:** Dust suppressants are chemicals or natural substances that can be applied to mining roads, haulage routes, and stockpiles to reduce dust generation. These include substances like lignosulfonates, calcium chloride, and polymer-based compounds.
- **Sustainability Aspect:** Many companies focus on using eco-friendly and biodegradable dust suppressants to minimise environmental impact.

3. Vegetation and Reclamation

- **Countries:** Australia, Canada, South Africa, United States
- **Description:** In mining operations where dust is generated from disturbed soil, vegetation is reintroduced through reclamation and rehabilitation efforts. Native plants are often chosen for their ability to thrive in the region and help stabilise the soil, reducing wind erosion and dust.
- **Sustainability Aspect:** Reclamation not only controls dust but also restores the ecosystem, improving biodiversity and water retention in the soil.

4. Dust Extraction Systems

- **Countries:** South Africa, Australia, Canada
- **Description:** In underground mining operations, sophisticated dust extraction systems are used to filter and remove dust from the air. These systems often involve ventilators, dust collection systems, and wet scrubbers to keep the working environment clean and safe.
- **Sustainability Aspect:** Modern extraction systems are designed to be energy-efficient and require minimal water and chemical usage, making them more sustainable.

5. Automated Haulage Systems

- **Countries:** Australia, Canada, Chile
- **Description:** In some mining operations, automated or electric haulage trucks and trains are used to reduce dust generation. These vehicles are equipped with dust suppression technology that reduces the amount of dust produced during transport.
- **Sustainability Aspect:** These systems also reduce fuel consumption and greenhouse gas emissions, contributing to overall sustainability goals.

6. Covering Stockpiles and Dumping Areas

- **Countries:** China, Australia, United States
- **Description:** To prevent dust from stockpiles, companies often use tarps, netting, or purpose-built covers. In some cases, they use misting or fogging systems to ensure that the stockpiles remain moist and don’t release dust.

- **Sustainability Aspect:** This approach helps reduce the amount of dust in the air while conserving water, particularly in areas where water scarcity is a concern.

7. Dust-Resilient Pavement Technology

- **Countries:** South Africa, Australia
- **Description:** Dust-resistant pavements are used in and around mining areas to minimise dust emissions from roads and surfaces. These pavements often use specific materials, like stabilised earth or asphalt mixtures, to reduce airborne dust.
- **Sustainability Aspect:** Reducing dust from roadways helps to lower environmental degradation while reducing the need for frequent re-surfacing, making it a more sustainable option.

8. Windbreaks and Barriers

- **Countries:** Chile, South Africa, Australia
- **Description:** Windbreaks, such as trees or artificial barriers, are used around mining operations to reduce wind speed and prevent dust from spreading. These natural or man-made barriers can effectively trap dust and reduce its dispersal.
- **Sustainability Aspect:** This practice improves air quality while providing environmental benefits such as habitat for wildlife and enhanced aesthetic value.

9. Monitoring and Remote Sensing

- **Countries:** Global (e.g., USA, Canada, Australia, Brazil)
- **Description:** Many countries use remote sensing technologies and air quality monitoring systems to track dust levels in and around mining operations. This data can be used to adjust dust control measures in real-time and ensure compliance with environmental regulations.
- **Sustainability Aspect:** The use of real-time monitoring helps to ensure that dust control practices are effective and that they can be adapted to changing conditions, reducing unnecessary environmental impacts.

10. Closed-Loop Water Management

- **Countries:** Australia, Canada, South Africa
- **Description:** In addition to using water for dust suppression, some mining companies have implemented closed-loop water management systems, where water used for dust control is collected, filtered, and reused, minimising water consumption and runoff.
- **Sustainability Aspect:** This practice ensures that mining operations are using water efficiently and reducing their environmental footprint, particularly in water-scarce regions.

By combining technology, ecological principles, and community involvement, mining companies are helping to reduce the harmful effects of dust while promoting sustainable development.

5. CONCLUSION AND FUTURE DIRECTIONS

This report underscores the persistent challenges and evolving strategies in the field of dust control within mining operations. During the assessment of coal mines for dust management, it was observed that mines generally fall into three categories. The first includes those where dust mitigation measures are available and effectively implemented, resulting in clean premises. The second category consists of mines where mitigation measures are available but were found non-functional during site visits. The third category includes mines lacking dust control devices altogether. From recognising the fundamental importance of dust mitigation to understanding the complexity of implementing effective systems, it is evident that this area remains both critical and multifaceted.

Dust concentration in mining environments is highly activity-specific and demands tailored mitigation strategies. Activities such as coal processing often result in immediate spikes in particulate matter (PM) levels, particularly at size reduction and crusher plants. These areas have been identified as key sources of fugitive dust emissions. Significant increases in dust concentration are observed when coal is fed into crushers, highlighting the need for effective control measures. Enclosing crusher units (isolation) and using water sprays within these units have proven successful in suppressing dust generation and preventing its release into the surrounding environment. Similarly, haul roads represent a major source of dust emissions. Effective dust control on these roads can be achieved through regular water sprinkling, along with improving the surface quality and structural strength of the roads using dust-resilient materials. These targeted interventions collectively contribute to a substantial reduction in dust levels across mining operations.

Direct emissions during coal production can be effectively controlled by implementing appropriate mitigation measures. These include the use of dust suppressants during excavation and blasting, as well as optimising blast design to minimise over-blasting and unnecessary dust generation. Additionally, adopting less fuel-intensive production methods - such as deploying automated heavy machinery and electric-powered vehicles - can further reduce emissions and improve environmental performance.

Greater emphasis is required on the handling of produced coal rather than solely focusing on dust generated during its production. Observations indicate that there is a higher potential for emission reduction during the coal handling stage, making it a critical area for implementing control measures.

Dust emissions from various activities are influenced not only by production capacity but also by the specific methods used in coal processing. Mines that employ cleaner processes tend to score higher, even with larger production volumes. Additionally, sites with effective dust mitigation measures in place consistently performed better in grading results. Furthermore, the coal supply chain and its transportation to various consumers emerge as major source of particulate emissions. A dedicated study into this aspect is essential. Implementing rapid loading systems and cleaner transportation methods can greatly reduce the release of airborne particles.

Dust carried by heavy vehicles onto public roads poses a serious risk to nearby residential areas, underscoring the urgency for operational wheel washing systems at exit points of mines. Additionally, vehicular emissions within mining zones must be systematically monitored.

The key insight is that while dust suppression remains a major challenge, it also offers a fertile ground for innovation and sustainable progress. The industry is gradually transitioning towards more sustainable, efficient, and technology-driven dust control solutions—not merely to meet regulatory requirements, but to foster a safer and more environmentally responsible mining sector. Embracing these advancements can pave the way for mining operations that are safer for workers and less harmful to the environment.

It is recommended to adopt advanced technologies such as monitoring and remote sensing, dust-resilient pavement technology, and the practice of covering stockpiles and dumping areas to improve air quality. The absence of covered stockpiles in the mines visited highlights an opportunity for immediate improvement, as covering these areas can significantly reduce the resuspension of fine particulate matter into the ambient air. Additionally, emissions from haul roads were found to be considerable in our research study, indicating an urgent need to implement dust-resilient pavement technology to effectively mitigate dust generation from these sources.

In addition to core mining activities, various allied coal-dependent industries thrive around mining areas. These industries, such as thermal power plants, coal coking, the steel industry, and smaller-scale coal use in restaurants and households, also significantly contribute to dust generation. Their impact on air pollution is often overlooked, yet they continuously exacerbate the problem.Moreover, allied coal-dependent industries such as coal washeries, coking coal plants and power plant contribute significantly to deteriorating air quality. These sectors warrant focused monitoring, as coal mining alone should not be held solely responsible for ambient air pollution.

Future Directions

- The study finds that variations in dust concentration within coal mines are activity-specific. Partial pavement of haul roads, coupled with regular watering and fogging, is an effective way to manage dust emissions. The highest levels of particulate matter (PM) were recorded at the coal crusher point. A significant spike in PM concentration occurs immediately when coal is fed into the crusher, indicating rapid dust generation. To mitigate this, dust suppression measures such as continuous water sprinkling during unloading and the use of tall curtains (isolation) around the crusher plant have proven effective in containing dust spread in the surrounding environment. Additionally, the use of wind barriers and suction hoods is proposed to capture coal dust emissions during crusher operations within coal mine premises.
- To reduce the spread of coal dust in local areas, a dedicated road network for coal transport is recommended. Establishing a centralized coal processing hub away from mine sites is also advised. Furthermore, relocating or phasing out the distribution of coal washeries and coke-producing units to a common hub outside residential areas is recommended.
- Regulatory authorities should mandate that mining and coal-dependent industries submit Business Responsibility and Sustainability Reports (BRSR) and Global Reporting Initiative (GRI) reports. These reports should be submitted on time and made publicly accessible.
- Dhanbad is surrounded not only by coal mines but also by allied industries such as coking coal plants and other small-scale coal-dependent industries, which significantly contribute to the city's poor air quality. Therefore, it is recommended that a separate study be conducted to assess the percentage of coal consumption by these industries, along with an analysis of the supply chain.
- Particulate matter generated during coal mining is just one component of total emissions, which also include emissions from coal transport, processing, and combustion by allied industries located around the mines. While PM emissions from production are largely contained within mine premises, dust spread into city and residential areas mainly arises from coal transportation. Therefore, effective air quality management must include controlling emissions across the entire supply chain, especially from road transport of coal to consumers such as washeries, coke producers, steel plants, and power stations.
- Additionally, the use of coal by the public for residential cooking and by small-scale industries such as restaurants and brick kilns also requires attention.

- A dedicated analysis is needed focussing on emission from mine fires & emission from consumption of coal by local public for residential and commercial purposes. .

- Road transport is a major contributor to overall pollution levels; therefore, exploring alternative modes for coal transportation, other than road is required.

- A detailed scientific study is needed to measure the dust profile in and around the coal mine during the mine operational time and during non-operational time

- A detailed scientific study is needed to quantify the dust profile in and around a coal mine during both operational and non-operational periods, to better understand the impact of coal production and transport on air quality. Another study should focus specifically on dust generated from overburden dumps due to wind action.

6. ANNEXURES

6.1 AGENDA OF CITY LEVEL IMPLEMENTATION COMMITTEE MEETING AND DISCUSSION ON SATURATION ACTION PLAN FOR FY 2024-25 AND 2025-26 UNDER NATIONAL CLEAN AIR PROGRAMME TO BE HELD ON 21.12.2024, DMC, DHANBAD.

Parameter	Levels in FY 2023-24 (µg/m3)	Target for FY 2024-25
PM10 levels	130	15% reduction on levels of 2023-24 or achievement of National Ambient Air Quality Standards (NAAQS)
Number of Good Days (AQI <200)	321	Increase in good days by 15% from 2023-24 or minimum achievement of 355 Good days

Table A1: Annual air quality reduction targets given by CPCB for FY 2023-24.

PM 10 (µg/m3)			Number of Good Days (AQI <200)			Score	Funds allocated in FY 2024-25	Eligibility of funds for FY 2024-25
2022-23	2023-24	Improvement	2022-23	2023-24	Improvement			
199	130	High	260	321	High	100	30 crore	100%

Table A2: As per CPCB, Dhanbad air quality performance in FY 2023-24.

i. Conduct regular checks on polluting vehicles, including verification of vehicle registration, insurance, fitness, driving licenses, and PUC certificates. (DTO).

ii. Conduct regular drives to prevent overloading of vehicles and ensure installation of weighing machines in mining areas such as BCCL, ECL, MPL, TATA, SAIL etc. (DTO).

iii. Fully concretise road stretches prone to high dust generation and routes used for coal transportation. (BCCL).

iv. Establish an IT-enabled Public Grievances Redressal System through an app. (JSPCB).

v. Establish an air quality forecasting system, and initiate a health-based programme to combat air pollution. (JSPCB).

vi. Review and validate the Source Apportionment Study prepared by NEERI, Nagpur for Dhanbad, with an Institute of Repute (IoR) nominated by MoEF&CC to assess its impact on air quality.

Figure 12: Sector-wise Distribution of Coal from Selected Mines.

7. REFERENCES

i. ACTION PLAN FOR CLUSTERS OF DHANBAD, https://cpcb.nic.in/displaypdf.php?id=REhBTkJBRC5wZGY=

ii. Automotive Research Association of India (ARAI), CPCB/MoEF. (2007). EF development for Indian vehicles, as a part of ambient air quality monitoring and emission source apportionment studies. AFL/2006-07/IOCL/Emission Factor Project/Final Rep. https ://www.cpcb.nic.in/DRAFT REPOR T-on-efdiv .pdf Central Pollution Control Board, Delhi, India. (2008–2010). Air quality monitoring, emission inventory and source apportionment studies for Indian cities. https ://cpcb.nic

iii. Banerjee, S. K., Dhar, R. K., & Ghose, M. K. (1996). Air pollution due to coal washery projects and its abatement measures. Environmental Management.

iv. Mrinal K. Ghose (2007). Generation and Quantification of Hazardous Dusts from Coal Mining in the Indian Context.

v. Kumar, U. (1995). Underground coal mining in India, challenges and prospects. Transactions of MGMI, 92(1), 1–7.

vi. Mathur, S. K. (1996). The energy prospective. Drilling and Exploration World, 6(1), 106–190.

vii. Mayer, M. (1965). A compilation of air pollutant emission factors for combustion processes, gasoline evaporation, and selected industrial processes. U.S. Department of Health, Education and Welfare, National Centre for Air Pollution Control.

viii. Nair, P. K., & Singh, B. (1990). Haul road dust consolidation in opencast mines - a new approach. Indian Journal of Environmental Protection, 10(1) 28–36.

ix. Clean Coal Engineering Technology Autho-Bruce G Miller,2010 https://doi.org/10.1016/C2009-0-20236-4

x. https://imma.org.in/wp-content/uploads/2023/12/ECL-Khottadih-Mass-prodn-technology-in-UG-coal-mine1.pdf

xi. NCAP: Final_Guidelines_State_Action_Plan_with_Annexure_171828132986546
https://prana.cpcb.gov.in/#/resources

xii. NCAP: Swachh Vayu Survekshan guideline for city ranking https://prana.cpcb.gov.in/#/resources

xiii. Guidelines for National Knowledge Network (NKN) and Institutes of Repute (IoRs) under National Clean Air Programme September 2022 https://prana.cpcb.gov.in/#/resources

xiv. Sarath Guttikunda , Nishadh K , Tanushree Ganguly , Puja Jawahar (2023): Plugging the ambient air monitoring gaps in India's national clean air programme (NCAP) airsheds www.elsevier.com/locate/atmosenv

xv. Tanushree Ganguly, Kurinji L. Selvaraj, Sarath K. Guttikunda(2020): National Clean Air Programme (NCAP) for Indian cities: Review and outlook of clean air action plans
http://www.journals.elsevier.com/atmospheric-environment-x