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Rock Discontinuities Impact on Quarrying and Mining of Industrial and Architectural Grade Rock Deposits with Sustainable Practices

Prof. D. Venkat Reddy* Prof T.N. Singh**

ABSTRACT

Rock discontinuities are the hidden seams within the Earth's crust—planes or surfaces where the rock fabric changes abruptly. These discontinuities such as joints, fractures, bedding planes, folds, faults, etc are weak planes to prove channel ways heat flow exchanges, and shear failures in surface and sub-mine slopes. Mega and microstructural discontinuities in natural rock deposits will make valuable rock deposits worthless. Some of these can be measured and influence the behaviour of the rock mass when placed under stress. These discontinuities in natural rock deposits play a significant role during stone quarrying, drilling, blasting, and development planning. A detailed mining geological map with lineaments is required to delineate mega and micro-discontinuities that may impact the workability of rock deposits. Advanced methods for preparing lineament maps using tools like Cartosat and satellite imagery are spot-on. Field analyses should consider both mega and micro discontinuities. These geological features significantly influence the economic recovery of rock deposits. Understanding them helps optimize mining operations. Sustainable practices must adopt the extraction of industrial rock deposits considering constructional, architectural, and export/import requirements. Innovative field studies and collaborative research involving all fields of experts using artificial intelligence (AI) must develop methodologies for evaluating rock-structural discontinuities before mining the rock deposits.

Keywords: Rock discontinuities, quarrying, mining, workability, sustainable practices.

INTRODUCTION

Rocks and stones are being utilised in infrastructural, construction, architectural engineering, and industrial applications. Civil engineering, architectural engineering, and industrial applications. Constructional engineers, architects, builders, and users have chosen and used attractive rocks and stones for their performance and durability. The usage of rocks and stones differs based on requirements, specifications, and rock engineering properties. All-natural rocks are not suitable for engineering architectural and industrial usage applications.

The geological diversity of Industrial/Architectural/ Commercial rock deposits of India

India's geological tapestry is a masterpiece woven across its diverse state States like Andhra Pradesh, Bihar, Gujarat, Madhya Pradesh, Maharashtra, Orissa, Rajasthan, Tamil Nadu, Telangana, Uttar Pradesh, and West Bengal contribute to this geological mosaic. Each region offers a distinct palette of rocks—igneous, sedimentary, and metamorphic. (Anon 2000) The Geological Survey of India (GSI), the Ministry of Mines, and the Government of India prepared an exclusive geological map of rock deposit locations in various states is presented in Figure 1.1

Indian natural stones have been used for centuries in constructing architectural marvels not only in India but in other parts of the world too. India also has an Indigenous resource of machinery and tool manufacturers that cater well to the demands of this sector. (Renjith and Venkat Reddy 2017).

India is a treasure trove of stone deposits. Our country probably has the largest reserves of granites and natural stones in the world. India accounts for 20 percent of the total world reserves. The Indian stone industry is spread

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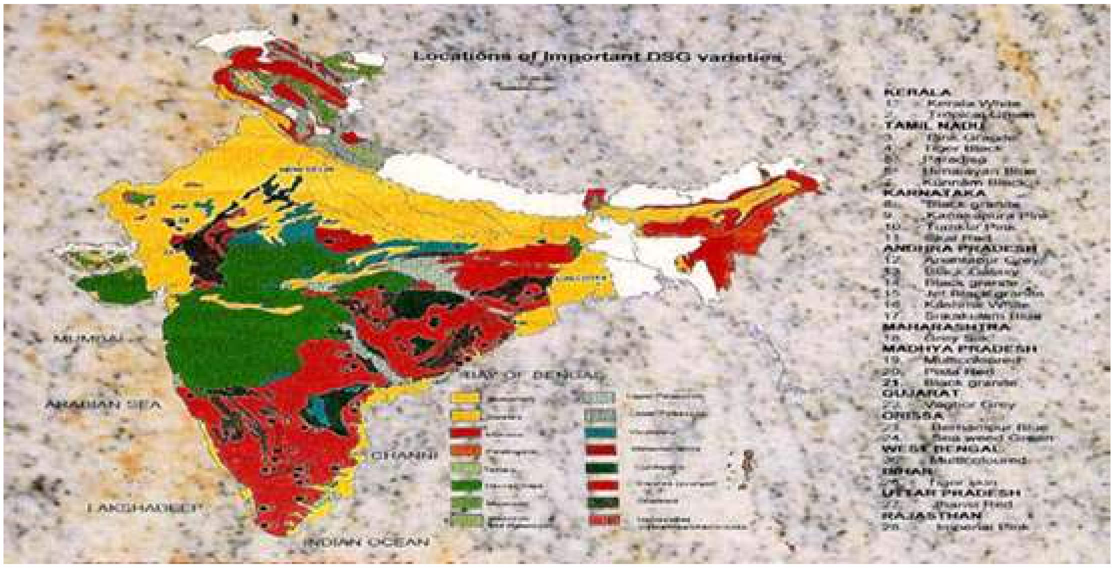

Figure 1.1 Industrial /dimensional rock deposits of India (Anon -2000) Source-GSI-granite dossier for information, 2000-Source GSI-govt of India-Ministry of Mines-2000):

throughout the length and breadth of the country. (Akhil and Venkat Reddy2015).

Knowledge of the physic-mechanical properties of rock is very important for the optional use of them as structural material. The Bureau of Indian Standards has developed many codes dealing with the procedure for the determination of mechanical properties of structural stones Engineering, architectural, and stone industries export and import require specific standards specified by National and international institutions before usage. Utilization of rock and stone requires detailed specifications and quality before mining or quarrying.

The success of the commercial decorative and dimensional stone industry solely depends upon the availability of large reserves of defect-free raw materials. It is uncommon to find that many stone entrepreneurs with all their commercial zeal have taken quarry leases started mining and abandoned them midway because of bad quality stones. Before taking a lease, an entrepreneur must take into consideration all the factors that govern the quality of the rock deposit (Kota Reddy, et al 1991).

ROCK DISCONTINUITIES IMPACT ON QUARRYING AND MINING OF INDUSTRIAL AND ARCHITECTURAL ROCK DEPOSITS WITH SUSTAINABLE PRACTICES

Rock is the basic building material of the Earth's crust and the original building material used by man from pre-historic times. In India, the use of stones for construction and architecture is as old as civilization. Despite its antiquity stone is regaining great popularity as a building material through a revolution in the art of quarrying or mining and processing. Field geologist explains the variety of stones' durability and occurrences. The ornamental stones are valued for their pleasing colour, durability, and amenability. The durability of decorative and dimensional building stone depends upon its physical and mechanical properties. In addition to field geologists, the stone industry is dependent upon a few specialists like mining engineers to masons and from architects to construction engineer." (Venkat reddy,2024)). The success of the commercial, decorative, and dimensional stone industry solely depends upon the availability of large reserves of defect-free raw materials. It is uncommon to find that many stone entrepreneurs with all their commercial zeal have taken quarry leases started mining and abandoned them midway because of bad quality stones. Before taking a lease, an entrepreneur must take into consideration all the factors that govern the quality of the rock deposit (**Kota Reddy, et al 1991**).

ROCK DEPOSITS FOR INFRASTRUCTURAL ENGINEERING: BALANCING WORKABILITY AND EXPORT POTENTIAL

Rock deposits utilized for civil engineering foundations, super structures of on-shore and off-shore structures, and industrial and architectural applications should be available in the workable form possible to extract specified dimensions. Rocks that are being quarried must be cut into specified dimensions as per requirement in engineering projects.

The workability of rock deposits depends upon the existing natural and inherent discontinuities. Massive crystalline igneous and metamorphic rock deposits are worked along with their joint, fracture, and sheeting planes as required dimensions. Bedded sedimentary rock deposits will be worked out along bedding planes for easy recovery. Massive rock deposits without joint or fracture planes will be worked out by creating artificial openings. The latest improved control blasting techniques are also being used for the mining and quarrying of specified dimension blocks without distorting adjacent rock deposits. Scientific methods and procedures are not being implemented by a few firms or individual quarry leasers leading to huge recovery losses and distortions of rock deposits internally. Such methods are affecting the quality of stone blocks and developing minor cracks and fractures finally resulting in rejected stone blocks. (Venkat Reddy,1994,1996)

LINEAMENTS IMPACT ON FAVORABLE AND UNFAVORABLE STRUCTURAL DISCONTINUITIES-ROLE SUGGESTING SUSTAINABLE METHODS FOR QUARRYING AND MINING OF ROCK DEPOSITS

Lineament is the linear feature in the landscape that reflects major structural discontinuity. Lineaments considered as mega structural discontinues. Satellite, Cartosat imageries, or aerial photographs make it possible to trace out major structural discontinuities of the terrain. Major landscapes, river valleys, faulted river valleys, straight river courses, and large igneous intrusions like dykes, sills, shear zones, etc., can be traced from satellite imageries or aerial photos. The latest enhanced software systems will facilitate tracing out discontinuity from space-based imageries (Ramasamy,2006). Lineaments map of South India extracted from satellite imageries interpretation. The typical lineament map of South India is presented in fig .2(Ramasamy,2006).

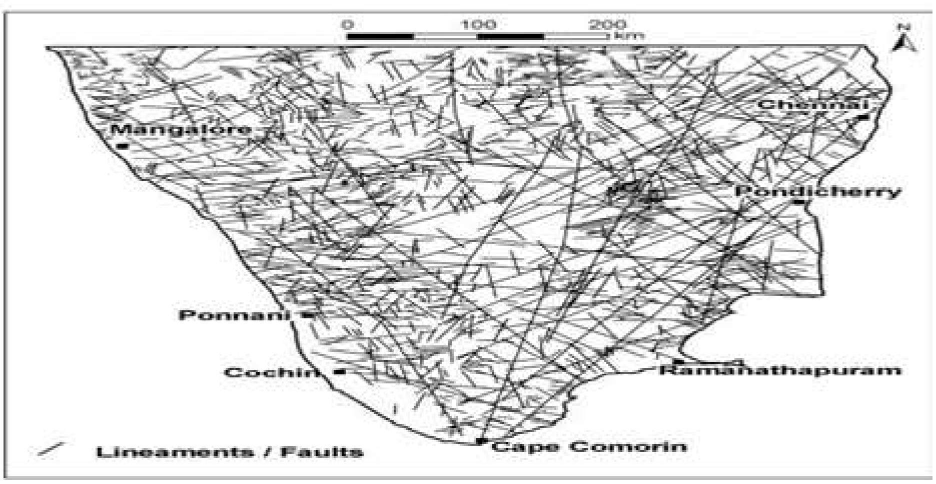

Fig 2-Lineament Map of Soth India-(after Ramasamy,2006)

QUARRYING /MINING OF DEFECTIVE FREE ROCK DEPOSITS -STRUCTURAL DISCONTINUITIES ROLE

Quarrying and mining of rock deposits depends upon the existing natural and inherent discontinuities. Massive crystalline igneous and metamorphic rock deposits are worked along with their joint, fracture, and sheeting planes as required dimensions. Bedded sedimentary rock deposits will be worked out along bedding planes for easy recovery. Massive rock deposits without joint or fracture planes will be worked out by creating artificial openings. The latest improved control blasting techniques are also being used for the mining and quarrying of specified dimension blocks without distorting adjacent rock deposits. Few firms or individual quarry leasers are not implementing scientific methods and procedures, leading to huge recovery losses and distortions of rock deposits internally. Such methods are affecting the quality of stone blocks and developing minor cracks and fractures finally resulting in rejected stone blocks.

The selection of decorative dimension stones suitable for exterior and interior decorations is one of the challenging tasks for geologists, and architectural, structural, and civil engineers. Therefore, understanding the knowledge of general properties of commercial-grade rocks and their quality assessment is most important before selecting stones for construction. (Manjunatha and Venkat Reddy, 2014)

Petro-genetical conditions of rock deposits play a significant role in the formation and workable factors. Quarrying of the rock deposits will be planned based on their extensions. The workability of rock deposits primarily depends upon the petrogenetic and structural parameters. In a geological setting rock deposits possess inherent natural discontinuities. These will play a significant role during the mining of rock deposits for specified dimensions. Natural rock discontinuities will impact during processing and polishing stones for required dimensions.

Fig 3. Favorable joint in granite rock deposit Chikmagalur, Karnataka state

UNFAVOURABLE STRUCTURAL DISCONTINUITIES IN ROCK DEPOSITS AND IMPACT RECOVERY

Closed-spaced joint patterns, minor faults, folds, shear zones, and low dipping foliations planes are considered unfavourable structural discontinuities. Recovery of rock deposits is inversely proportional to the density of joints

Detailed geological and structural studies of rock deposits must be carried out before quarrying or mining operations (Venkat Reddy, (2002)

Favourable structural discontinuities impact the workability of rock deposits

Generally favourable discontinuities suggested by Kaniskan (2004) include bedding planes, sheet joints, vertical joints, steep dipping, foliations planes, and magmatic structures, etc., These are generally favourable for the working of rock deposits. A detailed structural geological map of the proposed rock deposit is to be mapped and delineate/trace out the existing discontinuities which may favour for workability of the rock deposit. Massive granite rock deposits in Chickmagalur exhibiting favourable joints for extraction of the rock deposit are presented in figure3. Columnar joint in dolerite rock deposit Warangal exhibiting vertical joints for extraction is presented in Fig 4. (Venkat Reddy,2024)

Fig. 4. Favorable vertical joint in dolerite rock deposit, Warangal, Telangana state

in the rock deposits. If the density of joints is high, the recovery of rock deposits is low. It is necessary to assess the extent of the deep joint pattern of the quarry and rock deposit for economic recovery “(Kanishkan, 1995, 2004). Highly jointed pink granite deposits resulted in massive waste during quarrying presented in Fig 5. and multiple joints in granite rock deposits impacted on the presented in Fig 6 respectively.

Fig 5: Unfavourable joints resulted in a huge waste in granite quarry during blasting in Karnataka

Fig 6. Multiple, fractures in granite quarry

Continuous structural discontinuities: These include systematic joints, faults, master joints, folds, joint zones, cleavage, lineaments, and belts of lineaments. Industrial rock deposits that are impacted with continuous structural discontinuity are to be assessed in detail before mining operations. Rocks quality depends upon their compactness and free from continuous structural discontinuities.

Micro-discontinuities and stress minerals impact on recovery /mining of commercial rock deposits and impact on the recovery of the deposits

Micro-discontinuities—those tiny fractures and imperfections within rock deposits, and their masses—can significantly influence shear failure behaviour and recovery of the industrial rock deposit. Sustainable extraction of rock deposits depends upon the micro discontinuities and stress minerals. Economic and sustainable quarrying and mining of commercial rock deposits require assessing micro-and-stress minerals before planning quarrying/mining/blasting. In many field instances, huge rock waste is generated during quarrying and blasting. Understanding their distribution, orientation, and mechanical properties is crucial for safe quarrying and mining operations. In the field, stress minerals alter to form clay minerals. Clay minerals generally weakly bonded grains can exacerbate the impact on micro-discontinuities. (Pyrak-Nolte & Bobet (2024). Stress minerals impact the stability of micro-discontinuities in rock deposits resulting in undesired rock blocks and impacting the safe recovery. (Venkat Reddy, Vijayakumar, & Venugopal Reddy, (2005). When subjected to stress, these micro-features can propagate and lead to rock mass instability. understanding both macro- and micro-discontinuities is crucial for sustainable quarrying and mining. Proper blast design, monitoring, and responsible practices can minimize waste rock accumulation while ensuring safety and efficiency. (Rama Sastry and Venkat Reddy 2014). Understanding their distribution, orientation, and mechanical properties is crucial for safe quarrying and mining operations. Micro-discontinuities and stress minerals often impact the economic and safe recovery. (Venkat Reddy,1997 and 2024). Quality assessment techniques must be planned in mining commercial rock deposits before the quarrying and mining. (Venkat Reddy,1998)

CONCLUSIONS AND RECOMMENDATIONS ON SUSTAINABLE PRACTICES IN QUARRYING AND MINING OF ROCK DEPOSITS

i) Site-specific mining geological conditions: industrial and commercial rock deposit quarrying and mining operations should consider the specific geological conditions of the site. These conditions play a crucial role in determining the feasibility and safety of extraction.

ii)Advanced Lineament Mapping: Lineaments, which are linear features reflecting major structural discontinuities, are critical. Advanced methods for preparing lineament maps using tools like Cartosat and satellite imagery are spot-on. These maps help identify structural features that impact rock deposits.

iii)Sustainable Methodologies: Planning for safe and economically viable recovery of rock deposits is essential. Sustainable practices ensure that we balance extraction with conservation. Considering constructional, architectural, and export/import requirements is crucial here.

iv) Field Analyses and Discontinuities: Field analyses should consider both mega and micro discontinuities. These geological features significantly influence the economic recovery of rock deposits. Understanding them helps optimize mining operations.

v) Rock Deposit Variability: No rock deposit is truly continuous. Inherent structural discontinuities impact both surface and sub-surface stone quarry mining. Managing these variations effectively is key.

vi) Future Research and Innovation: Technical universities with artificial intelligence (AI) usages for quick data dissemination. Innovative field studies and collaborative research with the involvement of all fields of experts must develop methodologies for the evaluation of rock-structural discontinuities before the mining of the rock deposits

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Exploring the Synergy Between Safety and Sustainability to Shape a Safer and more Resilient Mining Industry for the Future

Prabir Kumar Palit*

ABSTRACT

Safety, sustainability, and environmental management are critical factors for the optimal utilization of resources and the pursuit of long-term prosperity while meeting the needs of future generations. These three facets are interlinked, and proper planning and execution are essential. The significance of sustainable development has been globally recognized, offering a roadmap to counter existential threats facing humanity. This paper explores the mismatches between safety, sustainability, and health in mining operations, which have led to the loss of precious mineral reserves that could have been better managed with proper coordination.

INTRODUCTION

Safety, sustainability, and environmental management are critical for ensuring effective resource utilization. These elements must be addressed cohesively for the betterment of current and future generations. The lack of coordination between these factors has often resulted in resource mismanagement. This paper discusses the consequences of poor integration of these elements and emphasizes their role in sustainable mining practices.

SAFETY AND SUSTAINABILITY IN MINING

Challenges in Mining Operations- Mining, one of the oldest professions, remains highly dangerous, particularly underground coal mining. Workers face risks such as asphyxiation, falling coal, inundation, dump and bench slides in opencast mines, and methane gas explosions. Methane, continuously released by coal seams, becomes explosive when mixed with air, leading to frequent mine explosions over the past decades.

Evolution of Mining Regulations- Since the introduction of the Mines Act of 1901, designed to regulate work practices in mines, the industry has advanced significantly. The transition from a primitive, labor-intensive sector to a mechanized one has enabled deeper resource extraction with greater efficiency. India, the second-largest coal producer globally, owes its status to a blend of government regulations, self-regulation, and strategic planning. Table 1 highlights India's position among the world's top coal-producing nations.

Table- 1

Year	CHINA	INDIA	USA	GERMANY	RUSSIA	POLAND	AUSTRALIA	SOUTH AFRICA	KHAZAKASTAN	INDONESIA
1990	1040	225	934	434	377	215	205	175	131	NA
2000	1355	336	972	205	242	162	307	224	77	79
2010	3316	570	996	184	300	133	436	255	111	325
2020	3789	754	486	107	404	100	493	247	103	566
2021	4012	825	524	126	438	107	455	229	107	616
2022	4430	937	540	131	440	107	459	225	109	690
2023	4,362.1	968.8	524.0	102.3	479.9	88.7	442.9	238.0	117.7	781.3
Ranking	**I**	**II**	**IV**	**VIII**	**VI**	**IX**	**V**	**VII**	**X**	**III**

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Over the past century, safety statistics have improved dramatically. The number of fatal accidents has plummeted, and modern accident investigations rarely attribute incidents to misadventure, a stark contrast to the conclusions reached a hundred years ago. Table 2 below illustrates the causes of accidents in two timeframes, separated by a century. It highlights that management responsibility, including that of supervisory personnel, is now identified as the primary cause in most cases, as evidenced by the data presented.

Table-2

Year	1912	1913	1915	2012	2013	2014
Misadventure	36.8%	44.1%	44.8%	4.9%	2.2%	2%
Management	28.6%	24.5%	14.7%	50%	57.8%	65%
Deceased	27.8%	24.3%	36.2%	13.1%	27.4%	3%
others	6.8%	5.1%	4.3%	32%	27.4%	30%

The mining industry is embracing "Smart Mining" by integrating state-of-the-art technology and innovative ideas to reimagine the entire value chain. This approach aims to enhance productivity, operational safety, and sustainability by leveraging advanced technologies and data analytics. Over time, this transformation will lead to more efficient resource utilization, reduced waste, improved profitability, and stronger stakeholder relationships. Digitalization plays a key role by enabling real-time equipment tracking, resulting in increased equipment efficiency and better traffic management. Data analytics is driving improvements through automated task scheduling, preventive maintenance, and cycle- time optimization. Additionally, the adoption of remote-controlled equipment for drilling and tele-remote loaders in certain mines is significantly boosting safety, improving safety statistics, and enabling the extraction of minerals at higher levels of efficiency.

In the coal industry, a consistent investment program and an increased emphasis on the application of modern technologies have enabled coal production to reach 893.19 million tonnes in 2022-23, increasing to 997.83 million tonnes in 2023-24.

Acknowledging the need for sustainable mining practices, Sustainable Development Cells have been established both at the Ministry level and within all coal/lignite companies. These cells aim to streamline efforts towards sustainability with uniformity and facilitate the sharing of best practices through knowledge and experience exchange. The sustainability initiatives focus on three key pillars: environmental sustainability, socio-cultural sustainability, and economic sustainability.

Coal companies are making consistent efforts to adopt world-class eco-friendly mining technologies, conserve natural resources, mitigate the impact of mining through appropriate measures, create income-generating opportunities and skill development programs, improve quality of life by providing essential infrastructure and services such as water and healthcare, and ensure ethical and transparent business practices.

These goals are achieved through initiatives such as better air quality management with dust suppression techniques, effective ventilation, bio-reclamation, land-use management, and the adoption of the star rating system. This system evaluates performance across seven key areas: mining operations, environmental parameters, best mining practices, economic performance, rehabilitation and resettlement, worker compliance, and safety and security standards.

SAFETY, SUSTAINABILITY, AND THEIR CONTRADICTIONS

The Interconnection Between Safety and Sustainability- Understanding the link between safety and sustainability is crucial for effectively implementing sustainable practices. This section addresses three key questions:

(i) How neglecting safety can negatively impact sustainable development.

(ii) How safety initiatives contribute to sustainability in practice.

(iii) Why integrating safety considerations during the design phase is essential for achieving sustainable development.

Progress and Challenges in Mine Safety- Despite notable advancements in safety statistics over recent decades due to the adoption of advanced technologies, significant challenges remain. A key concern is the apparent lack of commitment from mine operators, both in India and globally, to prioritize safety. Recent mining disasters, analyzed in this study, underscore the urgency for genuine and consistent efforts to address these shortcomings.

Safety Management Plans and Their implementations-
The Safety Management Plan (SMP) is a mandatory requirement under Regulation 104 of the Coal Mines Regulations, 2017, and is equally critical for metalliferous mines. However, historical evidence suggests that ignoring the safety-sustainability relationship can result in severe consequences, particularly as new technologies and products are adopted without adequate risk analysis.
Although most coal mines have developed SMPs, the lack of regular internal and external audits and also lack of corelation of the hazards including their ratings through Analytic hierarchy Process (AHP) remains a pressing issue. A review of some coal mine disasters highlights this contradiction, as the root causes frequently stem from inadequate implementation and oversight of safety protocols.

ANALYSIS OF CAUSES OF A FEW MAJOR MINE DISASTERS

Bhatdee Coal Mine Disaster - (Date of accident: 06.09.2006, Time: 1945 hours, Number of persons killed: 50 , Cause – Explosion)

The tragic accidents at the Bhatdee Mine in September 2006 occurred when an explosion occurred in the mine resulting in the death of 50 miners.

ROOT CAUSE ANALYSIS: SOME KEY OBSERVATIONS

(i) Poor Communication and Irresponsible Transfers
The inquiry identified that crucial mine officials, such as the Ventilation Officer, Safety Officer, and Assistant Manager, were all newly posted to the mine during the second week of August. Notably, the Ventilation Officer had been transferred to this degree-three mine after spending 18 years working in opencast mines. This highlights significant lapses in planning and oversight during the transfer and deployment of key personnel.

(ii) Unnecessary Management Structure
The mine's management structure was found to be overly complex, with multiple hierarchical levels: the Manager reported to the Agent, who in turn reported to the Additional General Manager, and finally to the Chief General Manager. This excessive layering contributed to delays in decision-making and a lack of clear accountability, undermining operational efficiency and safety.

(iii) Lack of Proper Supervision
Inadequate supervision was evident, as frontline workers such as Overmen and Mining Sirdars failed to carry essential safety equipment. Additionally, the Shotfirer neglected to use a methanometer before blasting, compromising safety measures and exposing systemic supervisory lapses.

Crandall Canyon Coal Mine Disaster - (Date of accident: 06.08.2007 & 16.08.2007, Number of persons killed: 6 miners + 3 rescue personnel including one Inspector of MSHA, Cause – Bump)

The tragic accidents at the Crandall Canyon Mine in August 2007 occurred when overstressed coal pillars suddenly failed, over a distance of ½ mile violently expelling coal from the pillars into the mine openings. Locally referred to in Utah as a "bounce," terminology for this type of event differs regionally, and is also known as an outburst, bump, or burst. The six miners working on the section likely received fatal injuries from the ejected coal as it violently filled the entries.

ROOT CAUSE ANALYSIS: SOME KEY OBSERVATIONS

(i) Defective Mine Design- The mine design failed to ensure effective control of coal bursts. Specifically:

Pillar Dimensions: Both the active workings' pillar dimensions and adjoining barrier pillars lacked adequate strength to withstand stresses.
Faulty Application: Analyses regarding pillar dimensions were improperly conducted, inadequately reviewed, and inaccurately reported.
Pillar Recovery Methods: Recovery methods produced dimensions incompatible with ground control needs, especially under the deep overburden and high abutment loading in the South Barrier section.

These design shortcomings contributed significantly to the occurrence of coal bursts.

(ii) Defective Communication- The operator did not take sufficient measures to prevent coal outburst accidents, including:

Failing to propose revisions to the roof control plan when it proved inadequate for controlling the roof, face, ribs, or coal bursts.

Ignoring clear warning signs, such as roof and rib burst damage, incidents of miners being struck by coal, and multiple unreported coal outburst accidents.

These failures suggest a breakdown in communication and accountability mechanisms, particularly in reporting to the Mine Safety and Health Administration (MSHA).

(iii) Excessive Extraction- Operations deviated from the approved roof control plan and pillar design parameters:

Mining occurred in prohibited areas (e.g., between crosscut 142 and crosscut 139 south of the No. 1 entry).

Pillars were mined to excessive heights through bottom coal extraction.

Entry alignments differed from the approved models, leading to compromised structural integrity.

These deviations likely exacerbated stress conditions and increased the risk of coal bursts.

Pike River Coal Mine Disaster– (Date of accident- 19.11.2010, Number of persons killed- 29).

On the afternoon of 19 November 2010, an explosion ripped through the remote Pike River mine on the West Coast of the South Island, killing 29 men. Their bodies have not been recovered, and remain in the mine.

ROOT CAUSE ANALYSIS: SOME KEY OBSERVATIONS

(i) Management problem- This was a process safety related accident, being an unintended escape of methane followed by an explosion in the mine. It occurred during a drive to achieve coal production in a mine with leadership, operational systems and cultural deficiencies.

(ii) Inadequate oversight of Health and Safety Regulator- Such problems coincided with inadequate oversight of the mine by a health and safety regulator that lacked focus, resourcing and inspection capacity.

(iii) Deficiency of legal framework-The legal framework for health and safety in underground mining is deficient.

(iv) Frequent change of managerial personnel- There were six mine managers in the 26 months before the explosion. There was also significant change in other management positions.

(v) Production before safety- At the executive manager level, there was a culture of production before safety at Pike River, and as a result, signs of the risk of an explosion were either not noticed or not responded to. The main fan failed in the explosion. It was not explosion-protected. A backup fan at the top of the ventilation shaft was damaged in the explosion and did not automatically start as planned. The ventilation system shut down. Methane sensors attached to machinery were generally well-maintained and calibrated to trip power at a set methane level. There was constant tripping on some machines, which led to the bypassing of sensors by some workers. Numerous contractors were engaged on a long-term basis. Contractor health and safety management was less effective. The induction and underground supervision of the smaller contractors, in particular, was lax.

(vi) Faulty incentive scheme- The management declared the workers had the incentive of a $13,000 bonus if they met production targets by late September, after which the payment would decrease from week to week. Despite a number of setup problems, the targets were met towards the end of the month. Production levels did not improve, and spikes in the methane levels continued to be recorded in the weeks leading up to the explosion.

Anjan Hill Coal Mine Disaster -(Date of accident- 206.05.2010, No, of persons killed- 14)

An accident occurred at Anjan Hill Mine of M/s South Eastern Coalfields Ltd in Korea District, Chhattisgarh State on 6th May 2010 at about 11:30 am causing death of 14 persons, inflicting serious bodily injuries to 5 persons and minor injuries to 26 persons.

Though the court of enquiry could not establish the cause of the disaster, it opined …"This (Firedamp explosion caused by spontaneous heating) may be a possibility, which can be confirmed after reopening of the mine Thus at this juncture of time, with the available data and circumstantial evidences and statement of eye witnesses it is not possible to arrive at a definite conclusion about the exact nature of the explosion and its genesis. The veracity of this (Bush fire) theory can, however, be established only after the assessment of travel path of explosion which must await till the mine is reopened and inspected critically before any significant disturbance of evidence left by the explosion".

ROOT CAUSE ANALYSIS: SOME KEY OBSERVATIONS

(i) Deficiency in information system- There was a deficiency in the information system for communicating useful information to higher authorities and all the concerned authorities/officers/persons without any delay, so that decision-makers could draw strategies for dealing with situations in the mines immediately.

Rajmahal Coal Mine Disaster - (Date of accident-29.12.2016, No. of persons killed- 23).

An accident occurred in Rajmahal Opencast Mines of M/s Eastern Coalfields Limited in District Godda of Jharkhand State on 29th December, 2016 causing loss of twenty three lives. During the operations in overburden dump, at about 07.00PM on 29.12.2016 a violent sound (boom) was heard followed by collapse of in-situ overburden, coal benches and slide of overburden dump. The slide, about 600m X 110m (4.31 M cu.m) in size (as per Report of HPC) was so sudden that it did not give any time to the workers deployed in the area to escape and consequently, 23 persons along with HEMMs got buried beneath the fallen materials.

ROOT CAUSE ANALYSIS: SOME KEY OBSERVATIONS

(i) Frequent Transfer and Posting of Senior-Level Management- From July 2016 to December 2016, frequent transfers and appointments of senior-level management—including the General Manager of Rajmahal, General Manager of Safety, Director Technical, and the Owner & Chairman cum Managing Director of Eastern Coalfields Limited—occurred without a system for handing over charges related to safety.

This lack of continuity forced officials to start afresh with every transfer.

For example, the Manager of Rajmahal, during a court statement, admitted joining in 2013 but being unaware of critical scientific studies conducted by CIMFR in 2011.

(ii) Improper Planning-The accident was essentially "designed to happen" due to poor planning.
The process of in-pit dumping was initiated and allowed to reach dangerous heights of up to 147 meters, setting the stage for the eventual accident.

(iii) Casual Attitude Toward Human Life in the Mine-The lack of sophisticated instruments and round-the-clock monitoring meant there were no systems in place to provide timely warnings of dump movement. Justifications for this oversight pointed to cost considerations: The estimated cost of loss of life was calculated at ¹ 20 lakhs per person, amounting to ¹ 460 lakhs for the loss of 23 lives.

A single Slope Stability Radar System, which could have prevented the incident, cost approximately ¹ 800 lakhs.

This demonstrated a troubling valuation of human life as being "cheaper" than preventive measures.

Piper Alpha Disaster (06.07.1988, No of persons killed-167)

Late in the evening of 06 July 1988, a series of explosions ripped through the Piper Alpha offshore platform in the North Sea. Engulfed in fire, over the next few hours most of the oil rig topside modules collapsed into the sea. 167 men died and many more were injured and traumatised.

ROOT CAUSE ANALYSIS: SOME KEY OBSERVATIONS

(i) Poor Communication-On Piper Alpha, communication between departments, shifts, and crews was personal, informal, and tailored to specific jobs. While this approach offered some benefits, it lacked standardization and minimum requirements:

The safety department failed to effectively convey critical information, resulting in a significant gap between intent and practice.

Communication failures were evident in the handling of suspended work permits, which were stored in the safety office rather than being displayed in the control room where they were immediately needed.

These deficiencies prevented smooth collaboration and heightened risks.

(ii) Deficiency in Training- Training programs for new offshore workers were severely inadequate:

Witnesses reported that if newcomers had prior offshore experience, their training was almost non-existent.

Safety induction was reduced to being handed a booklet, which was often outdated or irrelevant to the Piper Alpha platform.

Operators frequently failed to log maintenance activities, undermining accountability. Shift handovers, a critical time for communication, were poorly managed:
Occidental procedures required maintenance and operations teams to meet, inspect the worksite, and jointly sign off on permits.

In practice, operators were preoccupied with their own handovers, resulting in maintenance teams signing off permits and leaving them in the control room or safety office.

Lead production operators often neglected to review or discuss suspended permits, creating critical information gaps.

CONCLUSION

The above disasters in coal and oil mining industry, along with numerous others, provide clear evidence that while safety statistics have improved and mining companies have initiated efforts toward better safety and sustainability, managerial negligence, deficiency in proper communication remains a critical issue. This negligence has been an instrumental trigger for many avoidable disasters.

To achieve sustainable mining and a “zero harm” goal, the following measures are essential: Framing and Enforcing Safety Management Plans: Comprehensive safety strategies tailored to each operation.

Implementation of Principal Hazard Management Plans (PHMPs): Systematic identification and control of principal hazards to prevent catastrophic events and audit of the control implementations.

Adoption of Analytic Hierarchy Process (AHP): Prioritizing control measures effectively to allocate resources where they are most needed.
A holistic approach combining these measures will pave the way for achieving a sustainable mining industry that prioritizes the safety and well-being of its workers while meeting production goals responsibly.

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Engineering Control in the Perspective of Ergonomics

Dr N C Dey*

INTRODUCTION

The word "ergonomics" is derived from the Greek words ergon (work) and nomos (law). In US the term "Human Factors" is often used. It is the scientific discipline concerned with understanding of the interactions among humans and other elements of a system and the profession that applies theory, principles, data and methods to design and optimize human well-being and overall system performance.

AIMS OF ERGONOMICS

It aims to –
design appliances and technical systems
To improve
Human safety, Health, Comfort and Performance

- In the design of work and everyday life situations, the focus of ergonomics is MAN.
- Unsafe, Unhealthy, Uncomfortable or inefficient situations at work or in everyday life are avoided by taking account physical and psychological capabilities and limitations of humans.
- A large number of factors play a role in Ergonomics which includes –
- ➢ Body posture and movement (sitting, standing, lifting, pulling and pushing).

Environmental factors –
Noise
Vibration
Illumination
Climate

- ➢ Information and operation
- ➢ Work organisation (appropriate tasks)
- ➢ At work and everyday life, postures and movements are often imposed by the task and workplace.
- ➢ The body's muscles, ligaments and joints are involved in adopting a posture, carrying out a movement and applying a force (muscles provide the force necessary to adopt a posture or make a movement; ligaments have an auxiliary function, joints allow the relative movement of various parts of the body).

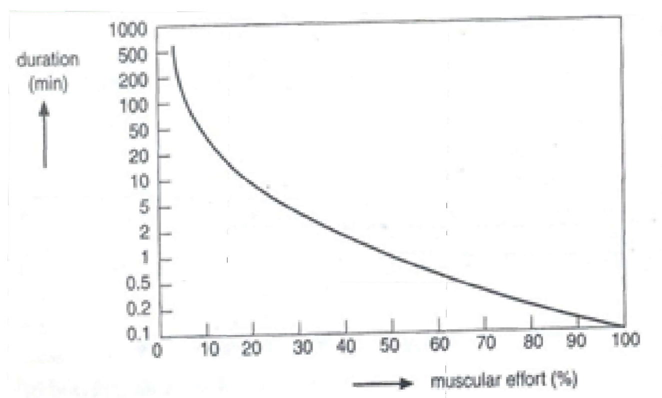
Muscle classification – Smooth muscle (stomach), Cardiac muscle (heart), Skeletal muscle (Biceps) which is a great interest of Ergonomists.

Poor posture can lead to –

Local mechanical stress on muscles, ligaments and joints resulting in complaints of the neck, back, shoulder, wrist and other parts of musculoskeletal system disorder. Some posture and movement also require an **expenditure of energy** on the part of muscles, heart and lungs.

BIO-MECHANICAL INTERVENTION IN HF ISSUE

Limit duration of any continuous muscular effort continuous stress on certain muscles in the body as a result of prolonged posture or repetitive movement leads to localized muscle fatigue. As a result the posture cannot be maintained continuously. The greater the muscular effort the shorter the time it can be maintained. In order to prevent Muscular Exhaustion the muscles will take fairly long time to recover if they become exhausted (see figure next).



The duration of continuous localized muscular effort must be limited. The figure shows the relationship between muscular effort (exerted force as a percentage of maximum force) and the maximum possible duration (in minutes) of any continuous muscular effort.

* *Professor (HAG), IIEST Shibpur*

PHYSICAL AND PHYSIOLOGICAL PARAMETERS

Weight, Height, BMI

Weights of the subjects are measured in kilograms by a sensitive human weighing machine and heights are measured in centimeters using an anthropometric rod. Body mass index is expressed in kg per m^2.

RESTING HEART RATE (HR RES)

The subjects are allowed to sit comfortably in a reclining position for atleast 30 minutes at the surface prior to their work before going down to mine. During this time heart rates are measured by stethoscope. The minimum heart rate recorded during this period is considered as the resting heart rate and expressed beats min-1.

WORKING HEART RATE (WHR)

It is accomplished both by using Mobile heart rate monitor [described later] (for drillers & dressers) and placing the stethoscope at the apex of the heart and the time counted for 10 beats by the stopwatch, which is then expressed in beats.min-1 (Astrand 1986, Anderson 1978).

WORKING OXYGEN CONSUMPTION: (WVO2)

Oxygen consumption during activity is obtained from Oxylog II machine by fitting the mask on the workers face and the portable instrument is fitted to their back. The value is directly collected visible on the liquid crystal display of the machine at least 5-10 minutes after the beginning of work for a considerable period of time.

NET CARDIAC COST (NCC)

NCC, the derived parameter is obtained as the difference of working and resting heart rate of the subjects and expressed in beats.min-1. **NCC = WHRav - RHR.**

RELATIVE CARDIAC COST (RCC)

This is the derived parameter obtained by expressing the heart rate at a given workload as the percentage of heart rate reserve (HRR)of a particular individual (heart rate reserve being the difference between maximal and resting heart rate) to depict the relative intensity of workload. It is calculated as**: RCC= NCC / HRR* 100.**

ENERGY EXPENDITURE (EE)

This is obtained by multiplying the working oxygen consumption by five as one litre of oxygen yields nearly five kilocalorie of energy where respiratory quotient is assumed as 1 (Das D 1993).

Environmental Parameters:

Direct and Derived Parameter in Mine A

	DB (°c)	WB(°c)	GT (°c)	NWB (°c)	WBGT (°C)	ET (°C)	RH (%)	Air Velocity (ft/min)
	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)
Day 1	25.75±0.29 (25.5-26)	23.75±0.29 (23.5-24)	25.12±0.25 (25-25.5)	23±0.0	23.64	23.52	84±0.0	15±5.77 (10-20)
Day 2	25.63±0.48 (25-26)	23.63±0.48 (23.5-24.5)	24.88±0.48 (24-25)	23±0.0	23.56	23.46	84±0.0	15±5.77 (10-20)
Day 3	25.63±0.48 (25-26)	23.75±0.29 (23.5-24)	25.13±0.25 (25-25.5)	23±0.0	23.64	23.5	85±2.00 (84-88)	15±5.77 (10-20)
Day 4	25.75±0.65 (25-26.5)	23.88±0.48 (23-24.5)	25.25±0.50 (25-26)	23.25±0.50 (23-24)	23.85	23.82	85±2.00 (84-88)	15±5.77 (10-20)
Day 5	26±0.41 (25.5-26.5)	24.38±0.85 (23.5-24.5)	25.5±0.41 (25-26)	23.5±0.58 (23-24)	24.10	23.92	85±2.00 (84-88)	15±5.77 (10-20)

Day 6	26.5±0.58 (26-27)	24.5±0.65 (24-25)	25.5±0.29 (25.5-26)	24.5±0.58 (24-25)	24.80	24.35	84±0.0	15±5.77 (10-20)
Day 7	26.25±0.65 (25.5-27)	24.37±0.48 (24-25)	25.62±0.48 (25-26)	25.25±0.96 (24-26)	25.36	24.98	85±0.34 (84-86)	15±5.77 (10-20)
Mean ± SD (Range)	25.93±0.34 (25.63-26.5)	24.04±0.36 (23.63-24.5)	25.29±0.26 (24.88-25.62)	23.64±0.89 (23-25.25)	**24.14±0.69 (23.56-25.36)**	**23.94±0.56 (23.46-24.98)**	84.57±0.53 (84-85)	15±0

Direct and Derived Parameter in Mine B

	DB (°c)	WB(°c)	GT (°c)	NWB (°c)	WBGT (°C)	ET (°C)	RH (%)	Air Velocity (ft/min)
	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)	Mean ± SD (Range)
Day 1	31±0.41 (30.5-31.5)	29.25±0.50 (28.5-29.5)	30.37±0.48 (30-31)	29.75±0.50 (29-30)	29.94	30.75	87.5±1.73 (86-89)	15±5.77 (10-20)
Day 2	30.88±0.25 (30.5-31)	29.38±0.25 (29-29.5)	30.50±0.41 (30-31)	30±0.0	30.15	29.98	89.25±2.87 (86-93)	15±5.77 (10-20)
Day 3	30.75±0.50 (30-31)	29±0.71 (28-29.5)	30.25±0.65 (29.5-31)	29.75±0.50 (29-30)	29.73	30.58	87.50±1.73 (86-89)	15±5.77 (10-20)
Day 4	30.63±0.48 (30-31)	28.75±0.65 (28-29.5)	30.25±0.65 (29.5-31)	29.50±0.58 (29-30)	29.90	30.88	86.75±1.50 (86-89)	15±5.77 (10-20)
Day 5	30.50±0.41 (30-31)	28.75±0.65 (28-29.5)	30.25±0.65 (29.5-31)	29.50±0.58 (29-30)	29.63	29.42	87.75±3.50 (86-94)	15±5.77 (10-20)
Day 6	30.65±0.52 (30-31)	29.5±0.65 (29-30)	30.5±0.72 (30-31.5)	29.25±0.58 (29-30)	29.73	29.52	88.20±2.34 (86-91)	15±5.77 (10-20)
Day 7	30.25±0.65 (30-31)	29.77±0.68 (29-30.5)	30.20±0.58 (30-31.5)	29.5±0.50 (29-30)	29.71	31.63	89.75±3.75 (86-94)	15±5.77 (10-20)
Mean ± SD (Range)	30.67±0.25 (30.25-31)	29.20±0.39 (28.75-29.77)	30.33±0.13 (30.20-30.50)	29.61±0.24 (29.25-30)	**29.82±0.18 (29.63-30.15)**	**30.6±0.18 (29.42-31.63)**	88.10±1.06 (86.75-89.75)	15±0

NON OCCUPATIONAL RISK FACTORS

- Age : The risk of developing CTS (syndrome) is higher among individuals over 40 yrs of age.
- Gender : Risk is high in women than men.
- Wrist Size : Individuals with small wrist size may be more susceptible to CTS.

ENGINEERING SOLUTION

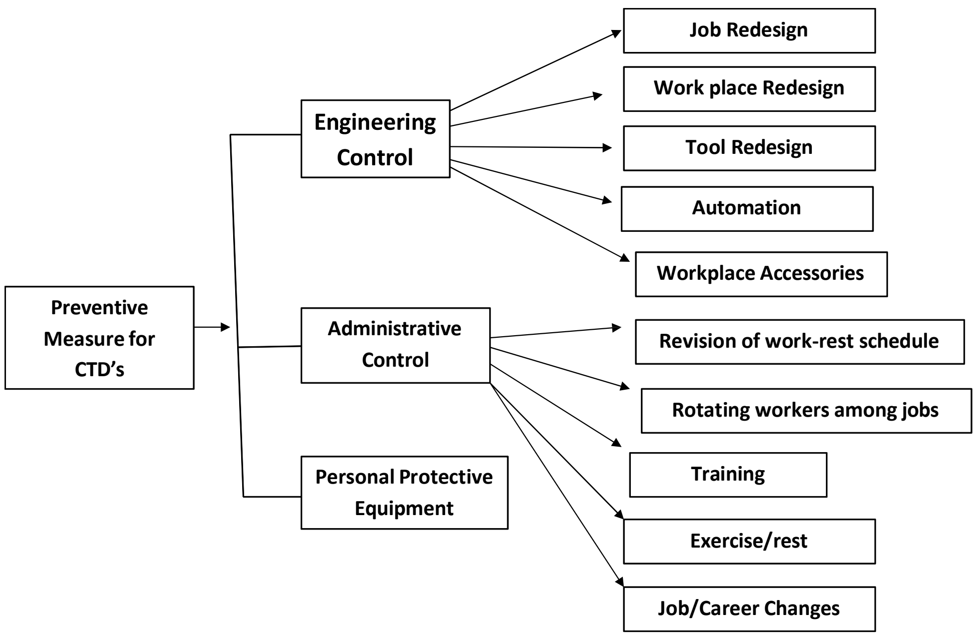
- Engineering solution are based upon ergonomic principles that are used to analyze repetitive motion tasks and to identify the stressful tasks. There are various engineering solutions each of which may be suitable for certain situation.

WORK PLACE REDESIGN

- Many musculoskeletal disorders are caused by awkward postures due to poor work place design.
- All work place in the problem should be evaluated

based on the ergonomic principles. The key solution is to design for neutral postures. Many situation merely need simple changes others may require significant changes in work place

- The work station should allow the workers to perform their job tasks in a comfortable body position.
- The body joints should be kept as close to the neutral position as possible during the job performance. This will minimize static loads on joints and the risk of development of CTD's caused by extreme or frequent movement.



CONCLUSION

The ergonomic control is extremely important to arrest the day to day problems of the workers. The work load of each category of workers must be determined to delay onset of fatigue which in turn maximize the production and productivity of mines. The application of ergonomics helps to adopt correct work posture to give comfort to the workers or supervisors for any unit operation. The adequate work-rest scheduling is a must for each spell of work to get maximum output from any person involved for the purpose.

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Illumination Survey and Design of Illumination Systems in Mechanized Opencast Coal Mine

Debi Prasad Tripathy* B.Mishra*

ABSTRACT

This paper comprehensively details out the findings of illumination survey conducted at a mechanized opencast coal mine of a public sector company vis-à-vis the illuminance standards prescribed by the Directorate General of Mines Safety (DGMS) at: haul road, dump yard, coal face, OB face, substation and various HEMMs. It also includes modification of illumination systems at different locations using software where illumination levels were found unsatisfactory.

Keywords: Illuminance, Opencast Coal Mines, Haul Road, Dump Yard, HEMM, DGMS

INTRODUCTION

Adequate lighting is essential for safety and production as it affects significantly efficiency and health of the individuals working in the mine. As per Directorate General of Mines Safety (DGMS) of India, the mine lighting should be designed and installed with proper lamps and fixtures that ensures uniform distribution of light on the work area for visual comfort and prevent glare and strain on the eyes of the workmen and work fatigue[1, 2]

To develop an effective and innovative illumination design, it is essential to thoroughly survey existing lighting system and check their adequacy against DGMS standards and if inadequate need to be redesigned for statutory compliance.

Design of adequate illumination system is desired to address illumination deficiencies and meet illumination standards as prescribed as per DGMS (Legis.) Circular No. 2 of 2017 dated 06/11/2017 on "Standards of Illumination in Opencast Coal Mines", Dhanbad[3].

STUDY AREA

The mechanized opencast coal mine is located in Talcher area of Odisha state and is operated by a reputed public sector company. The present production capacity of coal is more than 24MTY. The mechanized open-cast coal mining uses shovel-dumper combination for coal production and handling overburden. The mining is done both in departmental basis and contractual basis.

ILLUMINATION SURVEY IN MECHANIZED OPENCAST COAL MINE

The Luxmeter HD 450 was used for measuring the illuminance level in the selected opencast coal mine[4]. A 30m measuring tape is also used for measuring the distance between the poles, Illumination survey was conducted at haul road, dump yard, coal face, OB face, substation and various HEMMs. Illumination studies were conducted at different places of work during May 2024 and the values were compared with recommended DGMS standards. If found inadequate/overestimated, the illumination systems were redesigned using DIALux software.

Results of the Illumination Survey

Illumination Survey of Haul Road 1

The length of the haul road 1 was 1.8km; the interpole distance was 50m. There were HPSV lights on the poles throughout the road. Majority of them were in working condition. The wattage of the HPSV light was 400w. The length of the pole was 8m. The width of the road was 7m and the pole arrangement was of single arm type. The road was straight throughout. The figure of the haul road with lighting arrangements is given below in Fig.1:

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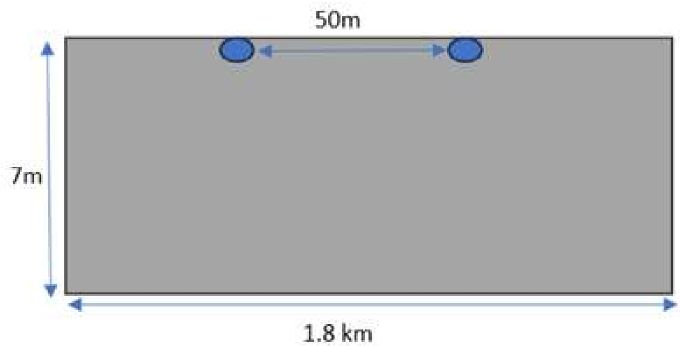

Figure 1: Position of poles in haul road 1

Illumination of Haul Road 2

The length of the haul road 2 was 1.5 km. The interpole distance was 50m. There were HPSV lights on the poles throughout the road. Majority of them were in working condition. The wattage of the HPSV light was 400w. The length of the pole was 8m. The width of the road was 14m and the pole arrangement was of single arm type. The road was straight throughout. The figure of the haul road with light arrangement is given below (Fig.2).

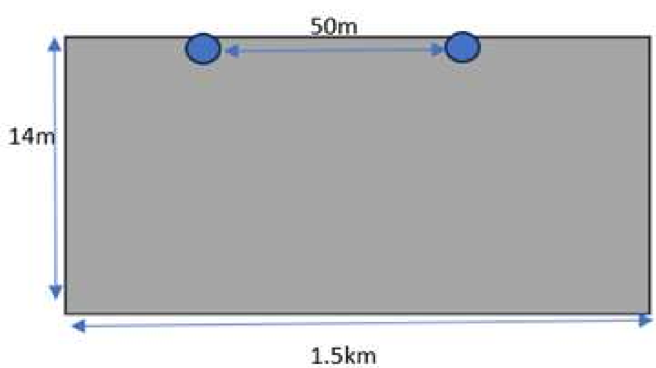

Figure 2: Position of poles in haul road 2

Illumination of Dump-yard-1

The area of the dump yard was 200m X 100m. There was mobile light tower which consist of 4 set of projector headlamps system of 1000w .Each system consists of 2 projector headlight. The height of the poles at the time of measurement was 8m. The figure of the dump yard-1 with lighting arrangement is given below (Fig.3):

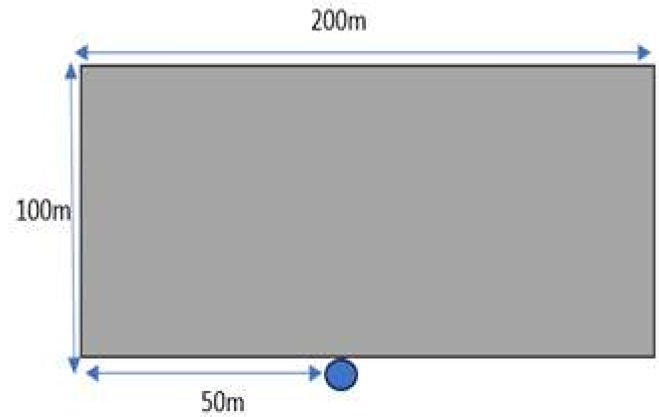

Figure 3: Position of poles in Dump Yard-1

Illumination of Dump-yard-2

The area of the dump yard was 50 X 30m. There was mobile light tower which consist of 4 set of LED system of 250w and 400w .The height of the poles at the time of measurement was 8m. The details of the dump yard-2 lighting are given below (Fig.4):

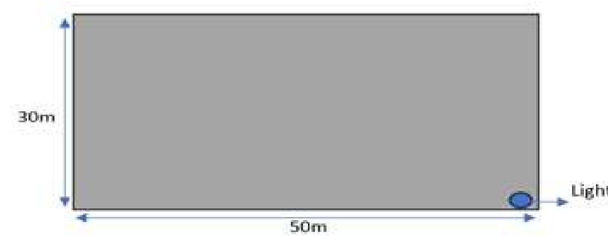

Figure 4: Position of poles in Dump Yard-2

Illumination Survey of Coal Face

The area of the coal face was 80m X 30m. There was mobile light tower which consist of 4 set of LED system of 250W and 400W .The height of the poles at the time of measurement was 8m. Table 1 shows results of illumination survey of coal face. The details of the coal face are given below (Fig.5):

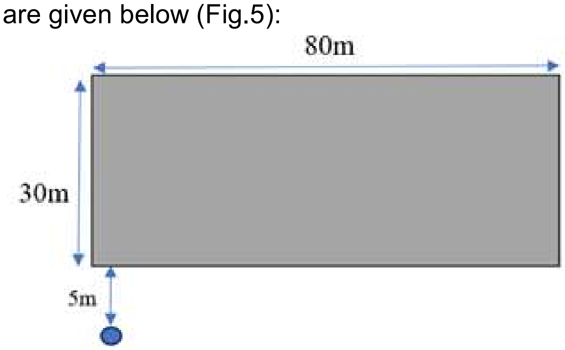

Figure 5: Position of poles in Coal face

Table 1: Results of illumination survey of BCML coal face

Distance from face (m)	Horizontal(lux)	Vertical(lux)
5	14.2	23.7
10	18	28.5

Illumination Survey of OB Face

The area of the OB face was 50m X 50m. There was mobile light tower which consist of 4 set of projector headlamps system of 1000w .Each system consists of 2 projector headlight .The height of the poles at the time of measurement was 8m. Table 2 gives results of illumination survey of OB face. The figure 6 shows details of the OB face lighting are given below:

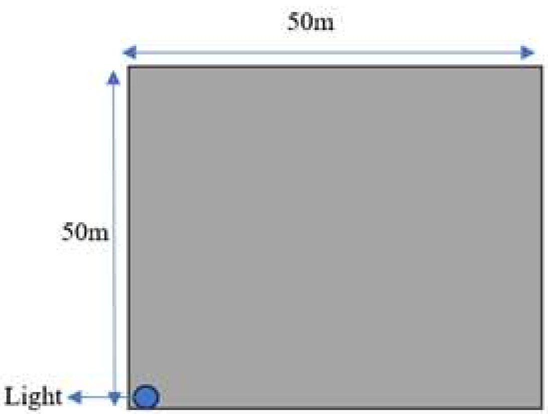

Figure 6: Position of poles in OB face

Table 2: Results of illumination survey of OB face

Distance from face (m)	Horizontal(lux)	Vertical(lux)
5	13.1	27.2
10	21.9	42.2

Illumination Survey of Substation Area

The area of the Substation was 50m x 50m. The height of the house was 5m. There were 2 LED lights installed in the roof top of wattage of 200w. Each pole consists of 2 LED lights. Table 3 gives results of illumination survey of substation area. The substation area lighting is given below (Fig.7):

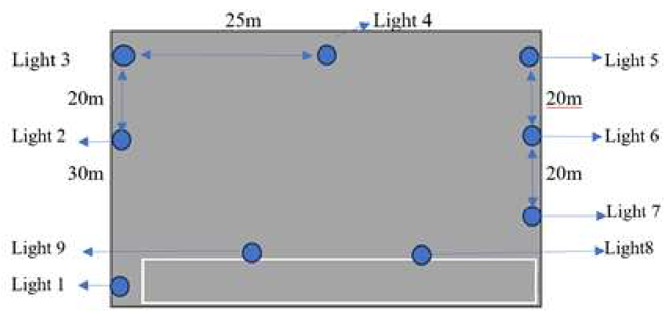

Figure 7: Position of poles in substation area

Table 3: Results of Illumination survey of substation area

Pole no	Pole height (m)	No Of lamps	Power usage (W)	Illuminance level (lux)		
				Distance around the luminaire	Horizontal illuminance Level (Lux)	Vertical illuminance Level (Lux)
1	8	2	200	5	103.6	54.6
2	8	2	200	5	84	109
3	8	2	200	5	30.6	80.5
4	8	2	200	5	87.2	80
5	8	2	200	5	63.9	84.2

Illumination of Cabins of HEMM

The illuminance measured in some cabins of dumper, drill machine and graders were below DGMS norms of 50 lux.

COMPARISON OF THE SURVEY RESULTS WITH THE DGMS STANDARDS

The summarized results of illumination survey at different places of work vis-à-vis the standard illumination (lux) values set by DGMS in their 2017 circular is presented in Table 4.

Table 4: Comparison of the survey results with the DGMS standards of illumination for opencast coal mine [3, 5]

Location	Minimum Illuminance in DGMS standard (lux)		Measured Illuminance (Average) in Lux		
	Horizontal	Vertical	Horizontal	Vertical	
Haul road 1	10	-	9	-	Marginally Unsatisfactory
Haul road 2	10	-	7	-	Unsatisfactory
Dump yard-1	15	25	24	88	Very high value
Dump yard-2	15	25	17.1	33.8	Satisfactory
Coal Face	15	25	16.1	26.1	Satisfactory
OB Face	15	25	17.5	34.5	Satisfactory
Substation	100	50	76	81	Unsatisfactory
Dumper	15	25	15.5	32	Satisfactory
Dozer Crawler	15	25	10	24	Unsatisfactory
Electric Drill	-	25	-	59	Satisfactory
Grader	15	25	25	42	Satisfactory
Dumper (cabin)	50	-	20		Unsatisfactory
Drill Machine (cabin)	50	-	25		Unsatisfactory
Grader (cabin)	50	-	16		Unsatisfactory

DISCUSSION

It is observed from Table 4 that haul road 1 and haul road 2, substation, and cabins of dumper etc. the illuminance levels were unsatisfactory. Illumination levels in dump yard 1 were too high and satisfactory in dump yard 2. In machinery working areas the illuminance levels were satisfactory.

MODIFIED DESIGN OF THE ILLUMINATION SYSTEM USING DIALUX SOFTWARE [5]

Design of Haul Road 1

The output of new proposed design of the haul road 1 is shown in Table 5 and the Isolux diagram is shown in Figure 8.

Table 5: Output for haul road 1

Parameters	value
Illuminance level, Em	12.55
Illuminance level, Emin	8.55
Uniformity ratio, Uo	0.68
Optimum pole spacing	50m
Arrangement type	Two-sided arrangement offset
No. of poles required	61
Power requirement,w	7686

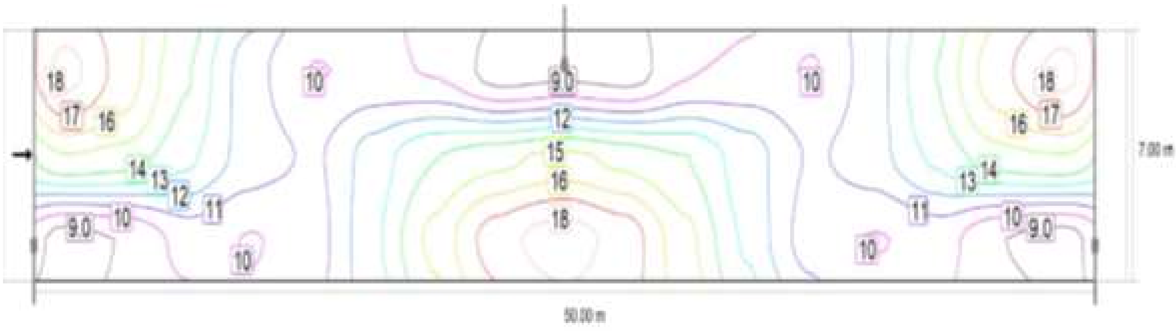

Figure 8. Isolux diagram of haul road 1

Design of Haul Road 2

The output of new proposed design of the haul road 2 is shown in Table 6 and the Isolux diagram is shown in Figure 9.

Table 6: Output for haul road 2

Parameters	value
Illuminance level, Em	11.20
Illuminance level, Emin	9.03
Uniformity ratio, Uo	0.81
Optimum pole spacing	50m
Arrangement type	Two-sided arrangement offset
No. of poles required	59
Power requirement	7434

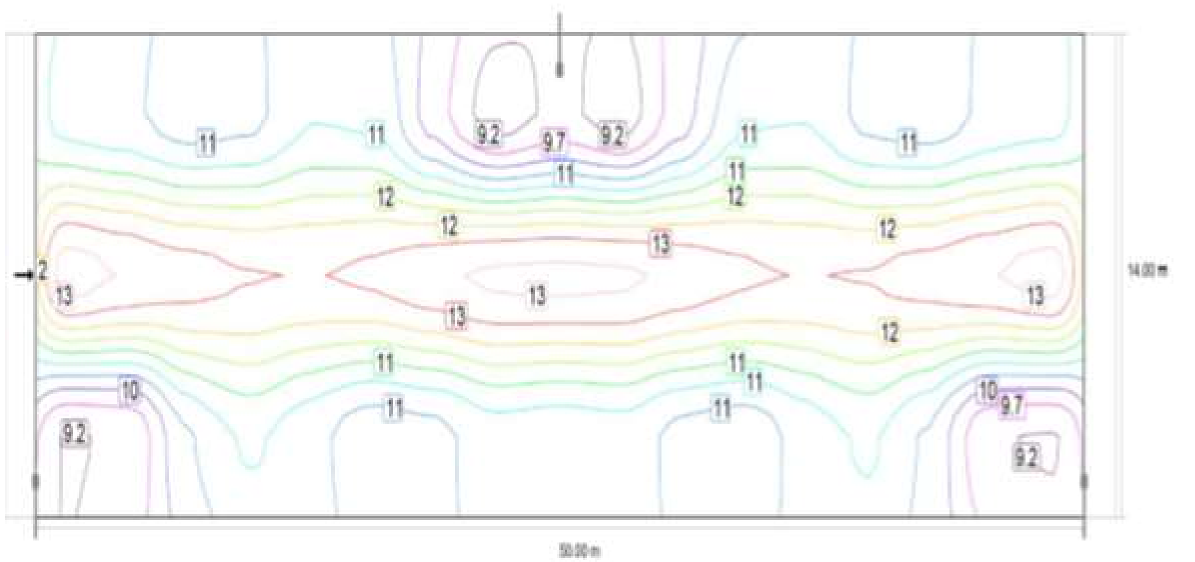

Figure 9. Isolux diagram of haul road 2

Design of Dump Yard 1

The area of the south dump yard is 200m x 100m.In the new design there are 31 poles of 10m. The total number of luminaries used is 46. The LED type of light is used having the wattage of 126W.The interpole distance of the luminaries in X axis is 25m and in Y axis is 16.7m. The output of new proposed design of the dump yard is shown in Table 7 and the false colour diagram of dump yard is shown in Figure 10.

Table 7: Output for dump yard-1

Parameters	value
average horizontal lux	15.7
Uniformity ratio	0.58
Total wattage requirement	5796

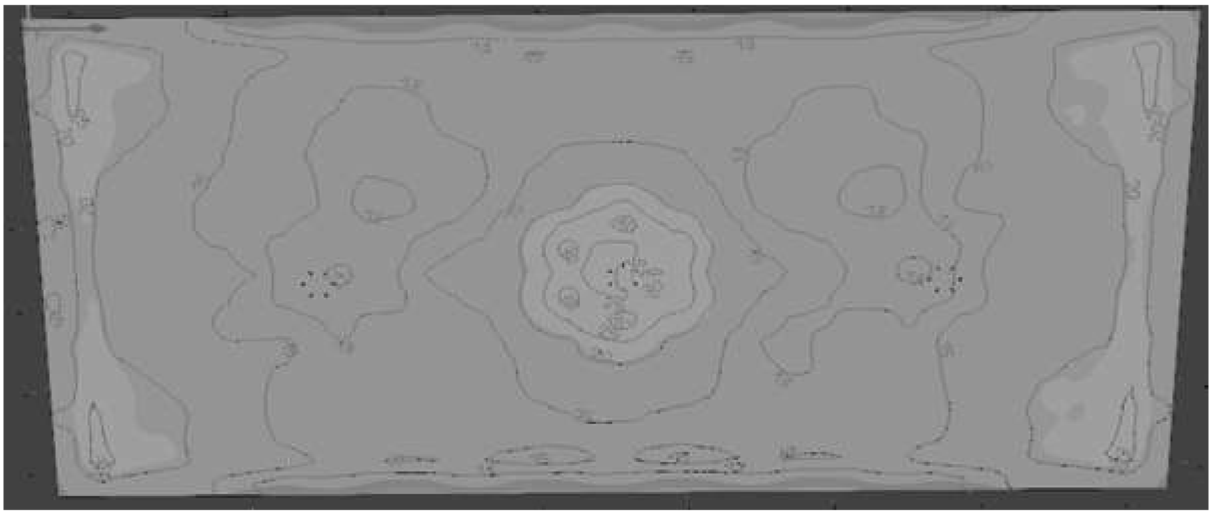

Figure 10: False colour diagram of dump yard 1

Design at Substation Area

The area of the substation area is 50m x 50m.In the new design there are 17 poles of 10m .the total number of luminaries used is 19. The LED type of light is used having the wattage of 200W.The interpole distance of the luminaries in X axis and Y axis is 12.5m. The output of new proposed design of the dump yard is shown in Table 8 and the false colour diagram of substation is shown in Figure 11.

Table 8: Output for substation area

Parameters	value
average horizontal lux	107
Uniformity ratio	0.86
Total wattage requirement	4066

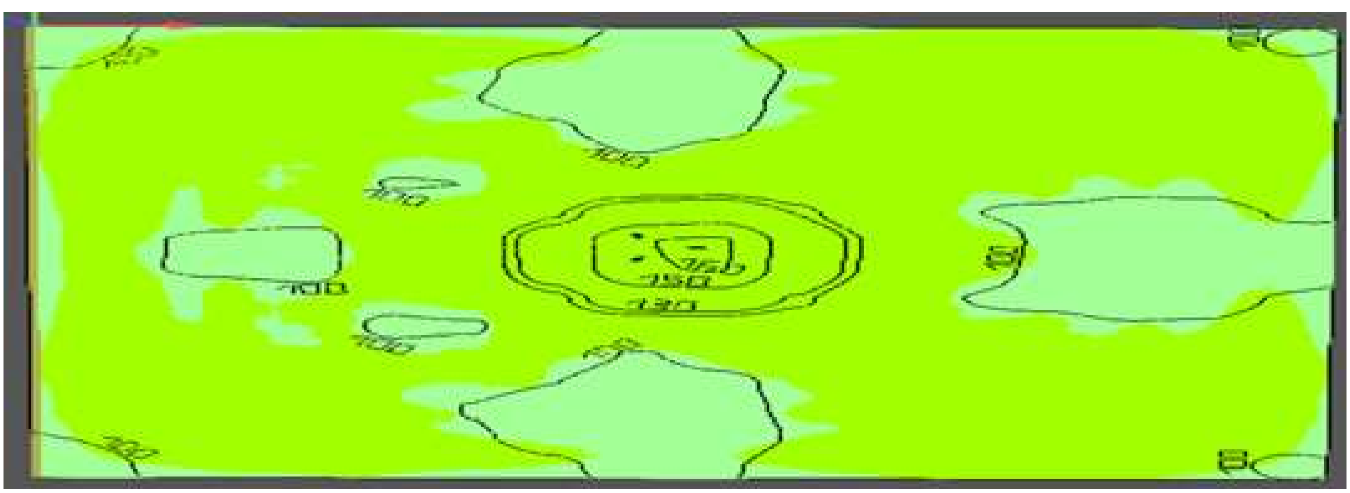

Figure 12: False colour diagram of substation area

Illumination Design in Cabin of HEMM

Based on cabin dimensions of HEMMs, 15W LED bulb with the lux value of the 60.1H lux was recommended for use that satisfies DGMS standards of 50H.

CONCLUSIONS

Based on the illumination survey carried out at the opencast coal mine, the following conclusions were drawn:

- For haul road 1, the measured lux level was 9 Lux, which falls short of the DGMS standard of 10 Lux.
- In haul road 2, the lux level (7 lux) was inadequate as compared DGMS standard (10Lux).
- In dump yard-1, the lux level (24) was very high as per DGMS standards.
- The dump yard-2 had an average lux level of 17.1, meeting the satisfactory criteria according to DGMS standards.
- The substation had a lux level of 76 which is unsatisfactory as per DGMS standards (100Lux).
- The coal face and OB face was satisfactorily illuminated with lux level as per DGMS standards.
- Illuminance level of cabins in HEMMs had inadequate lighting as compared to DGMS standard (50 Lux).
- Addressing the shortcomings of the current illumination levels at various work locations, an effective and improved lighting system was proposed using DIALux software.
- Haul road 1 and haul road 2 consisted of HPSV lights only.

Therefore, this case study proposes a new modified lighting system design for the haul road, dump yard, substation, and the cabins of various heavy earth moving machinery (HEMM). The following light wattages are suggested for the above stated place in the mine:

- Installation of 120w LED light in haul road 1 was done in two-sided offset arrangement with pole height of 8m and pole spacing of 50 m. The no of poles has been increased to 61 from 19. The wattage of lighting decreased from 400w to 120w. The pole spacing remains constant.
- Installation of 120w LED light in haul road 2 was done in two-sided offset arrangement with pole height of 10m and pole spacing of 50 m. The no of poles has been increased to 59 from 24. The wattage of lighting decreased from 400w to 120w. The pole spacing remains constant.
- In substation , 200w light is installed of pole height 10m ,the total no of poles has been increased from 9 to 17.The total no of luminaries used is 19, the wattage luminaire of new design is same as existing design.
- In dump yard-1, 120w LED light is installed with a pole height of 10m, the total number of poles has been increased from 1 to 31. The total no of luminaries used is 46.

The above modified design for various places of selected mechanized opencast coal mine was required to meet the illumination levels as mentioned in the DGMS standards with better light distribution.[5]

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Coal Characteristics and Paleoenvironmental Insights from the Karharbari Formation, Indian Gondwana

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ABSTRACT

The Karharbari Formation of the Indian Gondwana Supergroup plays an essential role in understanding the coal resources and geological history of the Early Permian. Well known for its unique lithological, paleontological, and coal characteristics, the Karharbari Formation is primarily associated with the Damodar-Koel Valley Basin but extends to the Mahanadi Valley Basin. Identified initially as the "Karharbari Stage" by Blanford (1878) and later redefined as a formation by Ghosh et al. (1964), it dates to the late Sakmarian-early Artinskian periods and serves as a crucial time-stratigraphic marker for correlating Lower Gondwana sequences in India. Deposited in a transitional environment from glacial to interglacial conditions, the Karharbari Formation is characterized by its feldspathic sandstones, grits, and conglomerates interbedded with coal seams and fireclays, reflecting fluvial-limnic interactions influenced by braided river systems and tectonic activity.

The coal within the Karharbari Formation is distinguished by its inertinite-rich composition, low ash content, and high calorific value, indicative of peat formed in well-aerated raised swamps with minimal terrigenous input. Geochemical analyses highlight the enrichment of Mn, Cr, and Fe, differentiating Karharbari coals from those of the overlying Barakar Formation. The mineralogical makeup of the sandstones, dominated by zircon and rutile, and the reworked clasts from the Talchir Formation suggest proximal sedimentary sources shaped by rugged topography and epeirogenic movements. Variability in coal seam thickness, ash, and moisture content across coalfields reflects the dynamic depositional environment and post-depositional processes. Notable examples include the low ash and high-quality coal of the Hutar and Talcher coalfields, contrasting with the high ash content of the North Karanpura Coalfield, which requires beneficiation for industrial use.

Tectonic influences, such as epeirogenic movements and basement irregularities, played a significant role in sediment deposition, evident in features like wedge-shaped fanglomerates and paleogullies. The depositional environment evolved through interactions between juvenile streams and limnic systems, occasionally influenced by marine conditions, as indicated by the presence of acritarchs, ichnofossils, and wave ripples in the Mahanadi Basin. This dynamic setting contributed to the formation of coal seams interbedded with coarse-grained sediments. Fossil evidence, dominated by glossopterids, supports the interpretation of swampy, low-energy ecosystems conducive to high-quality peat accumulation.

The Karharbari Formation also provides insights into the Early Permian paleoenvironment. The transition from the glacial deposits of the underlying Talchir Formation to the fluvial-deltaic conditions of the Karharbari Formation reflects climatic and tectonic shifts, characterized by temperate to mildly warm conditions. Coal deposition in low-subsidence back basins with stable swamp ecosystems fostered extensive oxidation of organic matter, resulting in inertinite-dominated coals. The organic composition, predominantly Type-III kerogen, and thermal maturity (VR $_o$ ***~0.81) suggest the potential for gaseous hydrocarbon generation.***

The Karharbari Formation exemplifies the interplay of geological, climatic, and tectonic processes during a critical period of Earth's history. Beyond its significance as a coal resource, the formation serves as a vital stratigraphic marker for understanding Gondwana sedimentary processes and provides valuable data for resource exploration, paleoenvironmental reconstruction, and economic development. Its distinct lithology, depositional environment, and coal characteristics highlight its importance for geological research and industrial applications.

Keywords: Karharbari Formation, Coal distribution, Coal characteristics, Depositional setting

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INTRODUCTION

The Karharbari Formation is an integral part of India's coal resources, renowned for its geological distinctiveness and high-quality coal deposits. This formation is part of the Gondwana Supergroup and is primarily associated with the Damodar Valley Basin, but it also extends to the Mahanadi Valley Basin. It was first identified as the "Karharbari Stage" by Blanford (1878) and later redefined as a formation by Ghosh et al. (1964), based on its unique lithological characteristics and mappability across coalfields. The Karharbari Formation dates back to the Sakmarian-Artinskian periods of the Early Permian, providing a critical time-stratigraphic marker for correlating Lower Gondwana sequences in India (Ghosh & Basu, 1967; Acharya et al., 1975; Sastry et al., 1977; Tiwari & Kumar, 2002).

Named after the village of Karharbari (24°10' N, 86°20' E) near the Giridih Coalfield (formerly known as Karharbari Coalfield) in Jharkhand, the type area is situated in the Damodar Valley Basin, where its lithological and paleontological characteristics make it significant for regional stratigraphy.

GEOLOGY

Lithology: The Karharbari Formation is characterized by its distinct lithology, differing from the underlying Talchir and overlying Barakar formations. It consists predominantly of grey to brown and mottled carbonaceous sandstones, grits, and conglomerates, interspersed with coal seams and fireclays. These sandstones are feldspathic, comprising angular to sub-angular grains of quartz and feldspar, which are often fresh and unaltered. Reworked clasts from the underlying Talchir Formation, such as shale and sandstone fragments, are frequently incorporated into the Karharbari sandstones. The heavy mineral assemblage of the Karharbari sandstones is notably distinct, with a dominance of zircon and rutile and the relative scarcity of garnet and tourmaline. This contrasts with the Talchir Formation, rich in garnet, and the Barakar Formation, abundant in tourmaline (Fox, 1934; Ghosh & Basu, 1967; Maithy, 1969; Acharya et al., 1975; Sastry et al., 1977; Raja Rao, 1987; Chandra et al., 2000; GSI, 2009; Chakraborty et al., 2020).

Geological Setting: The Karharbari Formation was deposited during the Early Permian, reflecting a transition from the glacial deposits of the Talchir Formation to a fluvial depositional environment. The rugged topography and dissected ridges of resistant basement rocks strongly influenced sedimentation patterns. These conditions led to the deposition of fanglomerates, pebbly sandstones, and coarse-grained detritus filling paleogullies within pre-Barakar Gondwana basins. Epeirogenic movements shaped sedimentation, particularly in the Auranga and Hutar basins, resulting in the formation of wedge-shaped fanglomerates (Raja Rao, 1987).

Depositional Environment: The depositional environment of the Karharbari Formation indicates a dynamic interplay between juvenile streams and limnic environments, resulting in coal seams often interfingered with proximal bar deposits. Low ash content in the coal suggests peat formation in raised swamps with minimal terrigenous input, influenced by nearby braided stream networks. While predominantly fluvial in origin (Bhattacharya et al., 2002), evidence of marine influence has been identified in the Karharbari Formation, including the presence of acritarchs, ichnofossils, coarse-grained sandstones, wave ripples, and phosphate salts in Mahanadi Basin coalfields. These features suggest occasional coastal marine to deltaic (paralic) depositional conditions, contributing to the coal beds and associated sediments (De, 2001; Goswami, 2002, 2008). This environment is consistent with temperate to mildly warm climatic conditions during the Sakmarian-Artinskian periods (Raja Rao, 1987; Chandra et al., 2000; Chakraborty et al., 2022).

COAL CHARACTERISTICS

Karharbari coal is characterized by its dull, homogeneous, and non-banded appearance, first noted in the Giridih Coalfield (Blanford, 1878). The coal is inertinite-rich, with inertinite content often exceeding 80%, and vitrinite content below 20%, indicative of extensive oxidation during coal formation (Raja Rao, 1987; Chandra et al., 2000; Acharyya, 2019). Classified as high volatile 'C' to 'B' bituminous, it exhibits low volatile matter and high vitrinite reflectance (Singh, 2016a, b; Panda et al., 2022). Geochemical analyses reveal an enrichment of Mn, Cr, Fe, Cu, Ni, Co, Ca, and Mg in Karharbari coals compared to the Barakar coals, which are richer in Zn, Cd, Na, K, and Pb (Senapaty & Behera, 2012). These attributes reflect unique depositional and post-depositional processes.

COAL DISTRIBUTION

The Karharbari Formation exhibits significant variability in coal seam thickness, ash content, and moisture content across different coalfields (see Figure 1), reflecting diverse depositional environments and geological controls (Raja Rao, 1982, 1987, Chandra et al., 2000; GSI, 2009; Acharyya, 2019, Chakraborty, 2022).

The Damodar-Koel Master Basin

Giridih Coalfield:
Lower Karharbari Seam: Thickness ranges from 1.74 to 6.85 meters, with ash content varying between 13% and 16% and volatile matter around 29%. This superior-quality seam, free from dirt bands, is suitable for both thermal and metallurgical applications but has been extensively mined, with reserves largely confined to pillars in some areas.

Middle Karharbari Seam: Thickness ranges from 0.1 to 1.57 meters, divided into two sections with a 3.70-meter parting, and ash content is moderate at 14% to 15%. The seam's semicircular outcrop and confined deposition suggest its utility for localized thermal coal applications.

Upper Karharbari Seam: Thickness varies between 0.27 and 1.42 meters, split into top and bottom sections in some regions, with ash content comparable to the Middle Karharbari Seam. While thinner and of lower quality, the absence of dirt bands enhances its mining feasibility for thermal use.

Saharjuri Coalfield:
Seam I to VIII: Thickness ranges from 0.66 to 9.40 meters. Ash content varies widely (12.5–45.7%), indicating uneven coal quality influenced by depositional environments.

Daltonganj Coalfield:
Moderate ash (11.1–23.5%) and moisture content (2.6–8.8%) make the Rajhara and Pandwa seams suitable for both thermal and coking applications. Seam thickness ranges from 0.25 to 3.11 meters.

Hutar Coalfield:
Low ash content (7.0–13.2%) and moderate moisture (6.0–13.6%) across seams make this coalfield particularly valuable for metallurgical use. Thickness ranges up to 2.36 meters.

Auranga Coalfield:
Seam I: Thickness ranges from 0.55 to 2.15 meters, with ash content varying between 11.5% and 23.2%, and moisture levels ranging from 6.3% to 10.7%. This highlights the moderate utility of coal from this field, suitable for specific industrial applications.

North Karanpura Coalfield:
The Karharbari Seam has significant thickness (1.92–10.40 meters) but high ash content (29.1–37.2%) necessitates washing for industrial applications.

Itkhori Coalfield:
The Four Seams exhibit limited thickness (0.15–0.60 meters), with ash content at around 14.0% and moisture content at 9.5%. Although thinner, the coal could serve niche industrial applications.

The Mahanadi Basin:

Talcher Coalfield:
Talcher Seam I: Thickness ranges from 1.0 to 12.0 meters, with low ash (10.5–12.8%) and moisture (6.9–7.4%) indicating high-quality coal.

Ib-River Coalfield:
Ib Seam: Thickness ranges from 2.29 to 10.3 meters, with moderate ash (13.5–23.0%) and moisture (6–15%).

These variations highlight the Karharbari Formation's economic significance, with certain seams, such as in Hutar and Talcher, exhibiting prime coking qualities, while others, like North Karanpura, require beneficiation to enhance usability.

COAL DEPOSITION

The Karharbari Formation represents a dynamic depositional environment characterized by interactions between fluvial and limnic systems during the Early Permian. This environment facilitated the formation of coal seams interbedded with coarse-grained sandstones, grits, and fireclays. Coal deposition occurred primarily in raised peat swamps with minimal terrigenous input, influenced by braided stream networks. These swamps were situated in low-subsiding back basins, providing stable conditions for organic matter accumulation and subsequent coalification (Raja Rao, 1982, 1987; Chandra et al., 2000; Singh, 2016a, b; Chakraborty et al., 2022).

The organic matter in the Karharbari coal is predominantly Type-III kerogen, which is gas-prone, with a moderate contribution from Type-II kerogen. Extractable organic matter (EOM) ranges from 2,600 to 4,900 ppm, and total organic carbon (TOC) values vary significantly (6.78% to 42.68%), indicating rich organic material favourable for hydrocarbon generation. However, low hydrogen index (HI) values (<180) suggest limited potential for liquid hydrocarbons (Mishra et al., 1993). Vitrinite reflectance measurements (VR_o ~0.81) indicate that the formation is in the catagenetic stage, suitable for generating gaseous hydrocarbons.

The coal seams within the Karharbari Formation demonstrate considerable spatial variability in thickness, ash content, and moisture, reflecting both depositional and post-depositional influences. Coal deposition was influenced by tectonic activity, sediment supply, and climatic conditions. The wedge-shaped fanglomerates and irregular basement configurations in basins like Auranga and Hutar point to tectonic controls during sedimentation (Raja Rao, 1987, Chandra et al., 2000). The low ash content in seams such as those in Talcher and Hutar reflects depositional environments with limited clastic input, suggesting raised swamps with relatively stable subsidence.

The coal seams in the Karharbari Formation, despite their variability, hold significant economic value. Seams in Hutar and Talcher are particularly notable for their superior coking and energy-producing characteristics. The organic composition and thermal maturity indicate the potential for gas production, particularly in coalfields like Daltonganj and Hutar (Mishra et al., 1993).

PALAEOENVIRONMENT INSIGHTS

The Karharbari Formation provides critical insights into the palaeoenvironmental conditions prevailing during the Early Permian. The sedimentary records and associated coal deposits reveal a transitional environment between glacial and post-glacial conditions, characterized by fluvial-limnic interactions and stable swamp ecosystems. The transition from the glacial deposits of the underlying Talchir Formation to the fluvial and nearshore conditions of the Karharbari Formation reflects significant climatic and tectonic shifts during this period.

The Early Permian climate during the deposition of the Karharbari Formation was temperate to mildly warm, transitioning from glacial to interglacial phases. This climatic setting supported the development of raised peat swamps, which were critical for coal formation (Chakraborty et al., 2022). The low ash content and high inertinite in Karharbari coal indicate well-aerated swamp conditions with limited clastic input and extensive oxidation of organic matter (Raja Rao, 1987). However, the evidence of marine influence in the Gondwana basins, such as acritarchs, ichnofossils, and wave ripples, indicates episodic coastal marine conditions that could have influenced sedimentary processes (De, 2001; Goswami, 2002, 2008). These marine footprints suggest periodic marine transgressions, which may have interacted with prevailing fluvial systems to shape the basin's depositional dynamics.

Irregular basement topography and tectonic activities, such as epeirogenic movements, played a significant role in sediment deposition. The formation of wedge-shaped fanglomerates and paleogullies in basins like Auranga and Hutar highlights the tectonic control on sedimentary processes during this time (Raja Rao, 1987, Chandra et al., 2000). These structural controls also influenced the localized thickness and distribution of coal seams.

The mineralogical composition of the Karharbari Formation sandstones, with a dominance of zircon and rutile and the presence of reworked clasts from the Talchir Formation, provides evidence of a proximal sediment source. This suggests that sediments were derived from nearby eroded uplands, with minimal transport, consistent with the rugged topography of the depositional basins.

The organic-rich nature of Karharbari coal, primarily composed of Type-III kerogen, reflects significant input from terrestrial vegetation in freshwater swamp environments. The presence of inertinite-dominated coal suggests extensive oxidation, possibly during periods of low water levels in the swamps (Raja Rao, 1987; Mishra et al., 1993).

Fossil evidence, including plant remains, suggests a rich ecosystem dominated by glossopteris flora, which thrived in the swampy and low-energy environments of the Karharbari basins. These palaeoecological conditions were conducive to the accumulation of high-quality peat, later transformed into coal with distinct geochemical properties.

CONCLUSION

The Karharbari Formation, an integral component of the Gondwana Supergroup, encapsulates the geological, paleontological, and economic significance of India's Early Permian period. Formed during the Sakmarian-Artinskian stages, it marks a transitional phase in Earth's history from glacial to post-glacial conditions. Distinguished by its unique lithological and paleontological attributes, the formation is a vital stratigraphic marker for correlating Lower Gondwana sequences. It is primarily located in the Damodar Valley Basin, with extensions into the Mahanadi Valley Basin, reflecting its wide spatial distribution and regional significance.

Lithologically, the Karharbari Formation consists of feldspathic sandstones, grits, and conglomerates interbedded with coal seams and fireclays, transitioning from the glacial deposits of the underlying Talchir Formation to a predominantly fluvial environment. Its mineral assemblage, dominated by zircon and rutile, highlights distinct sedimentary processes and proximal sources, further differentiating it from adjacent formations. The depositional environment evolved under the dynamic interplay of juvenile streams, braided river networks, and raised peat swamps, occasionally influenced by episodic marine incursions, as evidenced by acritarchs, ichnofossils, and wave ripples in the Mahanadi Basin.

Economically, the Karharbari coal is of high importance, characterized by inertinite-rich composition, low ash content, and high calorific value. This coal is classified as high-volatile bituminous and exhibits low volatile matter, indicating significant oxidation during coalification. Variations in coal seam thickness, ash content, and moisture across coalfields like Giridih, Saharjuri, Hutar, Talcher, and Daltonganj reflect the influence of localized depositional and tectonic controls. Certain seams, such as those in the Hutar and Talcher coalfields, are highly valuable for metallurgical and energy applications due to their superior quality, while others, such as the high-ash seams in North Karanpura, require beneficiation for industrial use.

Paleoenvironmentally, the formation provides insights into the climatic and tectonic shifts of the Early Permian. Raised peat swamps, stable back basins, and glossopterid-dominated vegetation facilitated the accumulation of organic matter, resulting in high-quality coal. Tectonic controls, such as epeirogenic movements and irregular basement topography, shaped sedimentary basins and influenced coal deposition. The thermal maturity of the coal indicates the potential for gaseous hydrocarbon generation, further enhancing its economic value.

In summary, the Karharbari Formation is a testament to the intricate interplay of climatic, tectonic, and sedimentary processes that shaped India's Gondwana basins. Its distinct characteristics, economic potential, and stratigraphic importance make it a focal point for geological research, resource exploration, and understanding the sedimentary dynamics of the Early Permian.

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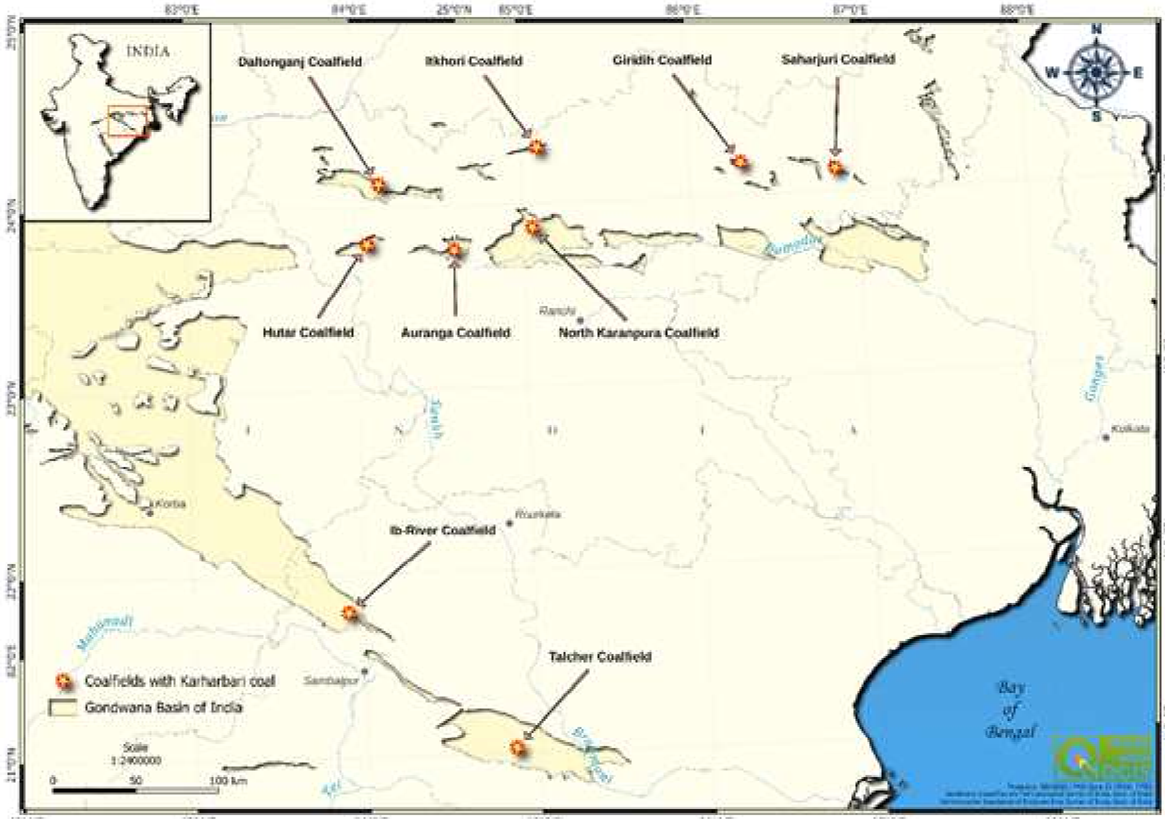

Figure 1. Coalfields with the Karharbari coal seams

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A Strategic Approach Towards Sustainability of Underground Coal Mining in India Through Large Scale Adoption of Mass Production Technologies

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ABSTRACT

Despite of serious concern world-over on the role of fossil fuels in general and coal based power in particular on global warming and climate change, India is very specific about its objective to use coal as the predominant contributor for the energy security of the nation at least till 2047 and even further. While India, as a signatory in the Paris Agreement, has given its firm commitment to reduce carbon footprint as a responsible global citizen by gradual substitution of fossil fuel based energy by 50% by 2030, later during COPS 26 at Glasgow in 2021, our Prime Minister has clearly deliberated on a modified strategy by enhancing coal based power generation to meet the needs of available and affordable coal resources in India for the foreseeable future, but of course without compromising with the basic commitment of reducing carbon footprint. Here comes the role of mining of coal as well as its utilization in such manner as to fulfill all these "apparently contradictory" conditions.

India as the 2nd largest producer of coal and with 4th largest reserve base has to plan very meticulously about the utilization of this natural resource in a sustainable manner. India is committed to enhance the per capita primary source of energy at least to the level of world average by 2030 and coal based power must play the main role in this respect. It is possible only if a properly designed sustainable coal mining and coal utilization policy is followed. It involves a techno-centric approach towards exploitation of coal with specific emphasis on adopting the principles of sustainable development framework for coal mining. The coal mining industry under the guideline of the Ministry of Coal, Government of India, is therefore keen to frame the major strategies towards implementation of these objectives. One of the important strategies in this direction is to enhance underground coal production in India by maintaining both qualitative and quantitative parameters and with safety, economy and environmental sustainability.

In this article, an attempt has been made to analyze the strategies developed in the highest policy making level of the nation towards sustainable coal mining practices through large scale adoption of Mass Production Technologies and also the means to implement those strategies in ground reality in the Indian context.

Keywords: Coal based Power; Energy security; Mass Production Technology (MPT); Sustainable coal mining.

INTRODUCTION

"The Underground Vision Plan of Coal India Ltd" has set a focal point of enhancing the production of coal from underground mines to the tune of 100 Million Ton by 2030 as a measure to gradually improve the status of underground coal mining in India in contrast to traditional unilateral dependence on opencast mining. At present, the contribution of underground coal mining in India is a mere figure of 4% only [1 & 2]. This paradigm shift is necessitated on account of the following basic considerations: Primarily, gradual depletion of opencastable coal resources and secondly, in comparison to opencast mining, underground coal mining is more environment friendly, socially acceptable and most importantly, paves the way for yielding superior quality coal from deep seated coal deposits in Indian context. Unlike in many leading major coal producing countries, India still preserves a huge reserve base of superior quality coal in comparatively deeper deposits between 300m to

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600m and 600m to 1200m depth ranges from the surface practically untouched. The energy security of India in the future decades will largely depend on efficient exploration and subsequent exploitation of these coal deposits. But the most important challenge lies in the selection of state of the art technologies in all phases of mining activities starting from modern exploration techniques to sustainable forms of exploitation of the coal seams and adaptation of clean coal technologies during the utilization of the extracted coal for generation of thermal power and other forms of coal utilization like Coal Gasification, Integrated Gasification Combined Cycle (IGCC) technology, commercial Coal Bed Methane (CBM) etc.

STRATEGIC ENDEAVORS FOR RATIONALIZATION OF UNDERGROUND COAL MINING IN INDIA

In the backdrop of present day scenario of underground coal mining in India a number of strategic endeavors are imperative at various levels of industry and administration.

(i) Exploration of comparatively large deposits of coal, which are not amenable by open cast mining methods. Any Mass Production Technology (MPT) requires high reserve of coal.

(ii) Planning of new mines only with deployment of MPT. Continuous Miner Technology is the MPT with B&P method of mining and at present in India there is wide scope of using the Continuous Miner (CM) technology mainly upto 350m depth of deposit. The other MPT, the Powered Support Longwall Technology, which can be used in most variable conditions, may be planned where the extractable reserves are very high starting from comparatively shallow depth to deep and very deep coal deposits.

(iii) Identification of more and more existing underground coal mines, presently working with intermediary technology (Drilling & Blasting in combination with SDL/LHD),where changeover to Continuous Miner technology is possible. This involves the real estimation of balance coal reserve in the mines, their existing infrastructure facilities and wherever required, modification and enhancement in infrastructure facilities to adopt higher level of mechanized mining methods.

(iv) Skill generation and development by training in high mechanization through organized class room and practical field exposure.

(v) An intensive industry, academia and research institutions interaction for conducting geo-mechanical and geo-mining studies for adoption of MPT in India-specific geo-mining conditions.

(vi) Development of vendors, initially for fast moving spares for adopted mass production technologies and gradually developing equipment manufacturing industries for state of the art UG mining technologies to reduce dependence on imports.

UNDERGROUND VISION PLAN OF COAL INDIA LIMITED

For enhancement of underground coal production, the following radical changes and interventions have been enumerated in the CIL vision plan-

(1) Conducting feasibility studies for more and more introduction of Continuous Miner Technology in underground mines

(2) Implementing large number of Highwall Mines wherever feasible to improve percentage of extraction of coal and to exploit the otherwise non-extractable coal resources in the old/discontinued/ running OC mines

(3) Transformation/revival of existing underground coal mines by replacing conventional mining technology with Mass Production Technology, mainly Continuous Miners subject to technical/feasibility study

(4) Identifying seams amenable to Longwall mining in virgin areas and within leasehold area of mines where upper horizons have been de-coaled and where possibility exists to extract lower seams.

(5) Enhancement in productivity by reengineering and amalgamation of current mines.

(6) Adopting the concept of composite pricing mechanism for assessing viability of underground mines, &

(7) Policy intervention for sale of coal produced from UG mines exclusively through e-auction route, specially for the coal grades of G10 and above.

While strategies mentioned in points 1-5 are technical in nature, strategies mentioned in points 6 & 7 covers the financial and commercial aspects.

ANALYSIS OF THE PERSPECTIVES OF THE MAIN MASS PRODUCTION TECHNOLOGIES IN INDIAN CONTEXT

As has been envisaged in the Underground Vision Plan of CIL, all the forms of Mass Production Technologies (MPTs) for UG coal mining have to play major and significant roles for enhancement of underground coal production in India which is the need of the hour for sustainable mining practices as well as the energy security of the nation. But the role of every such technology is distinct and different[3].

(1) Highwall mining: The role of highwall mining is very distinct and site specific. This is the mining method for extraction of remnant coal from the highwall bench side of an opencast mine, which can neither be efficiently or economically extracted either by extension of opencast mining or by general underground mining methods.

(2) Continuous Miner Mining- Continuous Miner (CM) Technology as a mass production technology applicable with B&P method of mining has got enormous scope in Indian underground coal mining sector. It has two very distinct directions. Firstly, new projects with Continuous Miner Technology with planning for high level of production, productivity and techno-economic parameters from the new project and secondly, revival or transformation of existing underground coal mines by replacing conventional mining technology with Continuous Miner Technology leading to enhanced production, productivity and techno-economic parameters, wherever feasible. But the applicability of this technology is limited to the specific geo-mining conditions suitable for efficient Bord &Pillar method of mining like depth range of deposits, nature of roof and floor of the coal seams being worked, degree of gassiness of the coal seams etc.

(3) Powered Support Longwall mining- Powered Support Longwall (PSLW) Technology has been globally acclaimed as the most versatile mass production technology for underground coal mining, which can be applied in the widest range of geo-mining conditions. The technology can be adopted at such shallow depth of hard cover as only 10 times the extraction thickness of a coal seam to any depth of deposit beyond 1000m & more. Practically beyond 400m depth, PSLW is the most suitable mining method from operational point of view. So far as roof strata are concerned, it can cover wide range of strata sequence from moderately hard strata to weak roof condition and practically , where the weak roof strata poses very serious challenge for B&P method of mining, PSLW technology provides the solution. In highly gassy coal seams, PSLW is the most suitable mining technology not only from the ventilation and environmental management point of view, but also from the point of view of effective control and monitoring for the explosion risk measurement and alleviation of the dangers associated with it. Besides the above stated, Powered Support Longwall Technology is the most productive with very high level of productivity and the safest globally accepted UG coal mining technology. In Indian context at present it is needed to identify the practical domain and scope for Powered Support Longwall Technology as a strategic measure to implement the underground vision plan of CIL.

SUSTAINABLE UTILIZATION OF COAL RESOURCES IN INDIA- THE REAL CHALLENGES

The sustainability concept brings forth the real challenges to be encountered in ground reality which can be expressed in the form of three bottom-line parameters, namely, Availability, Affordability and social and environmental Acceptability. In consideration of the three bottom line parameters of sustainability, the first two criteria pose immense strength in favor of coal in India. So far as social acceptability in terms of environmental impacts are concerned, radical changing scenario is presently in offing in India covered under Environmental Protection Act, 1986, Environmental Impact Assessment (EIA) notification under this Act and also by the need of stringent implementation of Environmental Management Plan (EMP) and Mine Closure Plan (MCP) for any new project or expansion of any existing project.

The sustainability principles further stress the need for and accordingly adopt the measures towards:

- Improved conservation of coal resources and continual improvement in reserve base
- Adoption of State of the Art technologies both for UG and opencast mining
- Mandatory Ecological Restoration covering three-tire plantation to ensure complete food chain restoration of flora and fauna in progressive and post mining scenario, back-filling of land mass by using preserved

top soil, proper treatment of affluent water for discharging in natural water courses etc.

- Emphasis on exploitation of improved quality of coal with higher GCV to facilitate burning efficiency of coal thereby reducing the emission of Green House Gases. In Indian context this leads to exploit the deeper deposits of coal compelling to strike a balance between opencast and underground mining of coal.
- Improvement in coal beneficiation both in terms of quantity and quality. It is envisaged to enhance the capacity not only for steel grade coking coal, but also for power grade non-coking coal from higher GCV and also environmental point of view.
- Exploring the potentiality of non-conventional methods of coal utilization like coal gasification-conversion to syngas as forms of cleaner energy sources, &
- Coal Bed Methane.

FULFILLING OF SUSTAINABILITY CRITERIA WITH THE LARGE SCALE ADOPTION OF MASS PRODUCTION TECHNOLOGIES OF UNDERGROUND COAL MINING IN INDIAN CONTEXT

Through adoption of Mass Production Technologies in underground coal mining only the sustainable utilization of the huge coal resources in our country can be ensured. This can be analyzed through the following discussions[4 & 5]:

(i) **Underground coal mining to supplement OC production**:- It has become imperative to strike a balance between the production of coal both from opencast and underground mines in India, which is feasible only with large scale implementation of mass production technologies for UG mining in Indian context. This involves use of all forms of Mass Production Technologies (MPT) of UG coal mining on the basis of site specific geo-mining conditions that would ensure higher level of production, productivity and techno-economical parameters of coal exploitation.

(ii) **Access to Deeper coal deposits**:- Unlike in majority of the leading coal producing nations, India is bestowed with a huge resource of improved quality power grade coal in comparatively deeper deposits between 300m-1200m depth range, which is practically untouched. This has created an enormous scope for exploitation of better grade coal by adaptation of mainly Powered Support Longwall Mining Technology in Indian coal mines. Large scale implementation of the Powered Support Longwall (PSLW) technology ensures highest level of production, productivity, techno-economics, safety, extraction percentage of mineral (Coal) and thus fulfilling the most important criteria of “Conservation of Mineral Resources”, all of which are key indicators of sustainability principles.

(iii) **Ecologically Friendly Mining**:- As a general rule, underground coal mining is more eco-friendly compared to opencast mining methods. The overall effect of underground coal mining on air, water and land environment is much less compared to opencast mining. Specially when we consider land environment in the context of India, it is the most critical as because with about 16% of world population in our country and only with 6% of the inhabited land property, we have the least per capita land of about only 0.1Ha. The situation poses more alarming when considered more than 45% of our population is directly linked with only agricultural activities. At present in India with practically unilateral implementation of opencast mining, the “Precious land property” is degraded at a rate of about 7Ha per 100 million ton of coal production. This implies enormous importance to underground coal mining in India in large scale.

(iv) **Improved coal quality to control Green House Gas Emission**:- The most important consideration towards sustainable utilization of coal resources in Indian context is that, the quality of power grade coal, which comprises the main constituent of Indian coal resources, is improved in deeper deposits, which are amenable to PSLW technology. It is an established fact that the emission of Green House Gases (GHGs) can be radically controlled with the improvement in coal quality and in Indian context this scope is enormous. The studies have shown that an improvement of 10% in the burning efficiency can lead to a decrease of more than 25% of GHG emissions. Further, with improved quality of coal obtained through UG mass production technologies, we can bring down radically the quantity of coal consumed for generation of 1 KWH of coal based thermal power from present day 700gm/KWH to closer to USA or Australia standard of 450gm/KWH. These parameters have far reaching effect on the sustainable use of coal resources in our country.

CONCLUSION

Sustainable utilization of coal resources is an extremely complex challenge requiring multi-dimensional approaches. Large scale adoption of mass production technologies for underground coal mining comprises only one of the strategic endeavors towards attaining the social and environmental acceptability of coal mining and coal based thermal power generation. It is undeniable that gradual reduction of fossil fuel dependence is an imperative for dealing with the all pervading objective of combating the challenge of global warming and climate change, but at the same time an outright rejection of fossil fuels is also not possible. In this perspective it is required to adopt techno-centric approaches towards sustainable utilization of coal resources which include multi-faceted strategic endeavors like development of “Clean Coal Technologies” and other alternative uses in the forms Coal Gasification and Coal Bed Methane.

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Laboratory Investigation of Stabilized Overburden Material for Mine Haul Roads

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ABSTRACT

Opencast mining is playing a major role in meeting India's fossil fuel demand for thermal power generation. Expansion of opencast mines, especially coal mines has led to the use of large-capacity haul trucks. The carrying capacity of haul trucks used in opencast mines has grown from merely 10 tonnes to 300 tonnes in recent years. The introduction of large-capacity haul trucks demands well-designed haul roads. At present, the design of new haul roads is based on experience and empirical methods. For maximum and efficient use of large-capacity haul trucks, it is necessary to provide a smooth haul road. A well-designed haul road ensures low maintenance as well as low operating costs. The structural design of the haul road determines the thickness of various layers of the road. The sub-grade/sub-base of haul road typically uses locally available material. It often results in potholes, rutting, etc. Opencast mining also imposes adverse conditions on the area due to substantial overburden lying unreclaimed. An investigation has been carried out to evaluate the use of mine overburden material along with a selected additive to develop an alternative engineering material to be used in mine haul roads. The composite M94RBI6 (94% murrum and 6% RBI) showed the highest strength values among all developed composites. All composites showed increased strength due to the formation of cementitious gel. Surface morphology confirmed the formation of hydrated gel and Ettringite rods due to the pozzolanic reaction.

Keywords— Haul Road Pavement, Opencast Mine, Mine Overburden, RBI grade-81, OMC-MDD, UCS, CBR, SEM

INTRODUCTION

A stable haul road plays an important role in maintaining the required production rate from an opencast mine as haul road failure creates frequent vehicular breakdowns, increased fuel consumption, and tire wear and tear (Mallick et al. 2016). Tannant and Regensburg (2001) observed potholes, and rutting on mine haul roads. Running dumpers on unstabilized haul roads contributes to huge dust generation (Cole and Zapert 1995; Amponsah-Decosta and Annegarn 1998; Reed et al. 2001), exposing mining personnel to health hazards. Stabilization of haul road is essential as transportation cost contributes up to 50% of total mining cost (Thompson and Visser 2003). Ulusay et al. (1995) classified the mine overburden material as heterogeneous. In Indian coal mining industry, haul roads are generally constructed from overburden materials like blasted sandstone, murrum, top-soil, and sub-soil from coal mine benches or from the waste dump. Waste dump is a collection of blasted overburden material dumped at one place which is a mixture of overburden materials like sandstone, shale, fireclay, murrum, and sub-soil. Murrum is a very hard homogenous massive material enriched with iron and aluminum. The lithology of a coalfield shows that the top soil is the outermost layer of soil and the subsoil is the layer under the topsoil. The problems associated with the haul road are stated by Mallick et al. (2016), Thompson (2011), Tannant and Regensburg (2001), Reed et al. (2001), Amponsah-Decosta and Annegarn (1998), and Cole and Zapert (1995). Sometimes, problems of haul road are due to introduction of large capacity dumpers on a haul road designed for lower vehicular capacity. In such cases enhancement of load bearing capacity of haul road is of primary importance.

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In this research, RBI grade-81 is used as a stabilizing material with the overburden material collected from mine benches. The motivation for use of this material came from comparative performance of four stabilizers (cement, lime, bitumen, and RBI) used with different soil type for civil engineering purposes. It is found that the RBI can be used for all types of soil. RBI is a cementitious material suitable for stabilization of every type of soil. It is calcium driven, inorganic soil stabilizer. The main components that are used to formulate RBI are a series of inorganic hydration activated powders. It is composed of a specific type of cement, a lime, several pozzolans, rate governing additives, and a unique polypropylene fiber. RBI is already established as a stabilizer for road construction by researcher like Kodicherla and Nandyala (2017), Kumar et al. (2015), Taib et al. (2016), Justo and Krishnamurthy (2008), and Geiman (2005). Generally, commercial additives like cement or lime augment the strength (Collins et al. 1986; Ghosh and Dey 2009; Mackos et al. 2009; Pandian 2004). Tannant and Kumar (2000), Cetin et al. (2010), Behera and Mishra (2012), and Mallick and Mishra (2017) developed fly ash- based composite material stabilized by kiln dust, lime kiln dust, lime, and clinker, respectively, for haul road construction. Krishna (2001) did XRD analysis of 3% cement stabilized fly ash and fly ash–black cotton soil mixture and found cementitious compounds. Lav and Lav (2000) mentioned that the strength enhancement is dependent on the magnitude of hydration products. Cetin et al. (2010) reported that the CBR of lime kiln dust-amended soil-fly-ash mixtures increased due to the formation of cementitious compounds. In this paper, individual samples of murrum, sub-soil, and top-soil are collected from the benches of a coal mine located in Odisha. The physical properties (like Atterberg's limits, particle size distribution), chemical properties, mechanical properties (like OMC, MDD, CBR (soaked and un-soaked), UCS and microstructural analysis are carried out for treated and untreated material. Comparison with the other composites developed for haul road pavement shows that the strength of the currently developed composite is better than the composite using waste dump material.

MATERIALS FOR STUDY

The base materials for this study are collected from coal mine benches of a large opencast mine located in the Mahanadi coalfields of Talcher area in Odisha state, India. Samples of murrum, top-soil, and sub-soil are carefully collected and sealed in airtight packets to preserve their inherent moisture content for laboratory study **(Figure 1)**. The climate in the area is generally dry and arid except in the monsoon season (June to September) with an average rainfall of 1329 mm per annum. It is characterized by extreme conditions, with summers being intensely warm and winters (December to January) rather cold with temperatures varying from 9.9 to 44.4 °C. The summer is severe during May–June when temperature rises as high as 49 °C accompanied by high humidity with average humidity varying from 26 to 83% and generally highest in August and least in March. RBI gives faster application compared to other commercial additives and provides a dust-free surface. It reduces pavement thickness, reduces aggregates consumption by 70%, construction time by 40%, and construction cost by 35%. It is non-toxic and non-leaching. It is eco-friendly and has a small carbon footprint.

Figure 1: Collection of Overburden Material

METHODOLOGY

In this study, nine composites are developed using three overburden materials and RBI for various tests as shown in **Table 1**. Nomenclature for composites is shown in **Table 1**. M96RBI4 represents 96% murrum with 4% RBI. Similarly, top-soil and sub-soil are represented by TS and SS. Samples from untreated murrum, top-soil, and sub-soil are prepared for various tests. Samples of treated overburden are prepared by adding RBI in various percentages like 2, 4, and 6 in dry state, and after that, water is added. Apart from chemical and microstructural analysis, physico-mechanical properties of three untreated and nine treated materials are cured for 7, 14, and 28 days. All tests for twelve material compositions are repeated thrice; hence, 288 physical and mechanical property tests conducted on these composites. The tests are carried out as per the prescribed Indian standards (IS) to determine Atterberg limits as per IS: 2720-part 5 (1985) and IS: 2720-part 6 (1972), grain size distributions as per IS: 2720-part 4, (1985), compaction characteristics as per IS: 2720-part 8 (1983), CBR as per IS: 2720-part 16 (1987) and UCS as per IS: 2720-part 10 (1991).

Table 1: Composite prepared for laboratory testing using overburden and RBI grade 81

OB material	OB (Weight %)	RBI grade-81 (Weight %)	Composite
Murrum	100	0	M100RBI0
	98	2	M98RBI2
	96	4	M96RBI4
	94	6	M94RBI6
Sub-soil	100	0	SS100RBI0
	98	2	SS98RBI2
	96	4	SS96RBI4
	94	6	SS94RBI6
Top-soil	100	0	TS100RBI0
	98	2	TS98RBI2
	96	4	TS96RBI4
	94	6	TS94RBI6

RESULTS AND DISCUSSION

In this section, untreated overburden materials are evaluated for their physical-mechanical-micro-structural properties. To enhance the strength properties, overburden materials are treated with RBI in various percentages. EDX analysis was carried out to determine the chemical composition of murrum, sub-soil, top-soil, and RBI **(Table 2)**.

TESTS ON UNTREATED MATERIALS

As per the unified soil classification system, murrum is classified as clayey gravels (GC) while sub-soil is clayey sands (SC) and top-soil is organic silty clays of low plasticity (OL) based on particle size analysis **(Table 3)**. Murrum contains 37.4% gravel; sub-soil contains 73.37% sand while top-soil contains 56.88% silt and clay. Atterberg's limit like SL reflects shrinking due to extraction of water. Holtz and Gibbs (1956) categorized the volume change characteristics based on PI and SL. Material with lower shrinkage limit (SL) and higher plasticity index (PI) is not suitable for a pavement material because of high potential of volume change. Results from laboratory test shows that murrum, sub-soil, and top-soil have low to moderate volume change potential **(Table 4)**. In India, most of the opencast mines experience both arid and humid atmosphere with a wide variation of temperature.

Table 2: Chemical compositions of O/B and RBI Grade 81

O/B & Additive	SiO_2	Al_2O_3	Fe_2O_3	CaO	K_2O	MgO	TiO_2	Na_2O	MnO	SO_3	H_2O	Fibers	Additive	LOI
Murrum	33.82	33.70	26.11	0.65	2.49	0.54	2.09	0.15	0.45	--	--	--	--	--
Sub-soil	54.80	25.87	9.83	0.62	2.69	0.67	1.88	--	--	--	--	--	--	3.64
Top-soil	51.48	26.96	5.89	1.21	1.71	0.59	2.37	--	--	--	--	--	--	9.79
RBI	16.4	6.1	1.9	56.2	0.1	0.9	--	--	0.1	10.2	3.1	0.8	4.2	--

Table 3: Particle Size Distribution of untreated overburden

Property	Murrum	Sub-soil	Top-soil
Gravel (> 4.75 mm)	37.40	--	--
Sand (4.75 mm-0.075mm)	35.23	73.37	43.12
Silt and clay (< 0.075 mm)	27.37	26.63	56.88
Classification (Unified Soil Classification System)	GC	SC	OL

Table 4: Physical properties of untreated and treated overburden

OB material	Composites	Liquid Limit	Plastic Limit	Plasticity Index	Shrinkage Limit
Murrum	M100RBI0	46.1	19.1	27	15.13
	M98RBI2	44.64	20.49	24.15	19.69
	M96RBI4	43.17	22.83	20.34	21.28
	M94RBI6	41.63	25.15	16.48	22.87
Sub-soil	SS100RBI0	24.6	NP	--	20.83
	SS98RBI2	21.63	NP	--	24.51
	SS96RBI4	20.12	NP	--	26.47
	SS94RBI6	18.37	NP	--	27.83
Top-soil	TS100RBI0	32.78	16.15	16.63	19.61
	TS98RBI2	30.54	18.45	12.09	23.86
	TS96RBI4	29.13	21.02	8.11	25.12
	TS94RBI6	27.22	23.34	3.88	26.92

Note: NP – Non-plastic

TEST OF TREATED OR COMPOSITE MATERIALS

Table 4 shows the physical properties of the treated and untreated material. Laboratory investigation revealed that the Atterberg limit of composite materials change significantly after addition of RBI. LL and PI decreased whereas PL increased with the increase in RBI percentage. This is because of reduction in thickness of double diffuse layer due to increase in electrolyte concentration of pore fluid. The thickness of double diffuse layer is inversely proportional to valency of exchangeable cations and electrolyte concentration of pore fluid. Similar results are reported by Sivapullaiah and Jha (2014). Plastic limit, related with inter-particle shear resistance, increases with the increase in inter-particle resistance due to rise in ion concentration, increase in the viscosity, and flocculation of the clay particles (Mitchell 1976). A soil with shrinking potential is generally problematic and difficult to handle. SL of mine overburden materials increased with increase in RBI percentage as shown in **Table 4**. With addition of RBI the stability of the soil increased drastically due to generation of inter-particle bond. Similar results are reported by Dash and Hussain (2012).

COMPACTION CHARACTERISTICS

Nicholson et al. (1994) mentioned that it is essential to achieve the desired degree of compaction to obtain the augmented strength. It is understood that mechanical properties like UCS and CBR are dependent on density and level of compaction. The moisture content of developed composites varied between 6 and 11%. The MDD of murrum with 2% RBI is highest and equal to 2130 kg/m^3 whereas the MDD of top-soil with 6% RBI is lowest and is equal to 1940 kg/m^3. The MDD of untreated murrum, sub-soil, and top-soil are 2055 kg/m^3, 1990 kg/m^3, and 1974 kg/m^3, respectively. The MDD is highest for murrum and lowest for top-soil as murrum contains gravel where as top-soil contains clay and silt. **Figure 2** shows that the MDD of treated overburden material decreases with an increase in RBI percentage. This decrease in MDD can be attributed to the replacement of soil with lightweight admixtures. A decrease in MDD due to the flocculation is due to the interaction between the particles and their groups. It is known that flocculated structure as a result of the formation of cementitious bonding makes the compaction more difficult owing to the greater shear resistance at the particulate level. RBI simply replaces the clay particles. Similar results are reported by Kodicherla and Nandyala (2017).

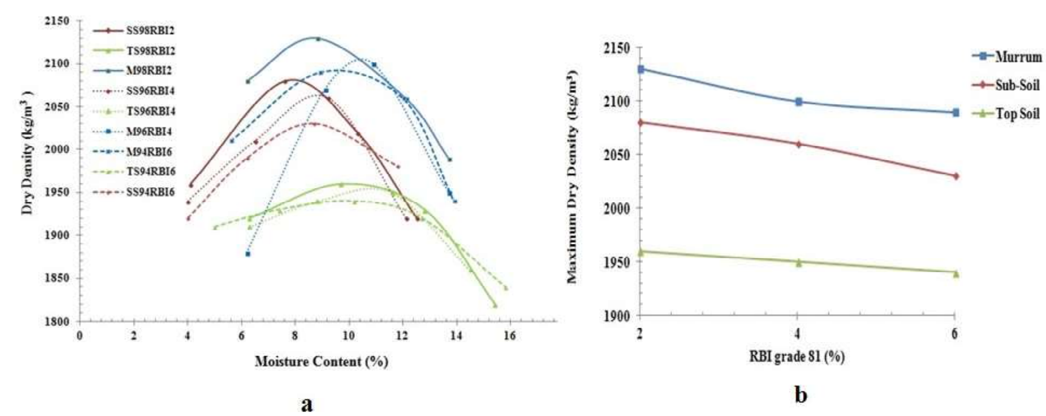

Figure 2: a Variation of dry density with moisture content. b Variation of maximum dry density with RBI

CALIFORNIA BEARING RATIO

Murrum showed high CBR value due to presence of gravel, offering more resistance to penetration. In un-soaked condition, CBR values of untreated overburden material varied between 4.7 and 39.3%. When the overburden materials are tested after 4 days of soaking, the CBR values obtained were very low. As per Bowles (1992), CBR value less than 3% is unsuitable for haul road construction. In such situation, overburden material should be stabilized to achieve desired CBR value. **Figure 3** shows CBR plot for soaked condition. Murrum exhibited

CBR value of 62.6% at 2% RBI and increased further with the increase in RBI. Thus, confirming that availability of CaO adds to strength gain. Maximum CBR value obtained is 200.12% for the composite M94RBI6 at 28 days of curing as shown in **Table 5**. The result shows that curing period and RBI percentage have strong effect on augmentation of the strength of composites. It is observed that the CBR value increased from 81.34 to 183.81% and 91.68 to 200.18% at 7 and 28 days of curing, respectively, as RBI percentage increased from 2 to 6% for murrum. Thus, increase in curing period contributed to increase the CBR value as hydration of RBI forms cementitious gel due to pozzolanic reaction between overburden material and RBI. The composite M94RBI6 showed highest CBR values among all developed composites at 7 and 28 days of curing, respectively. The obtained CBR values are comparable with the CBR values of the overburden stabilized with 10 to 40% of F-type fly ash and 2 to 8% of clinker cured for 28 days (Mallick and Mishra 2017). **Figure 3** shows a typical plot between stress and penetration for composites developed with murrum. It is clear that with the increase in RBI, the stress required for penetration increases. The gain is maximum for top-soil (up to 31.94) followed by sub-soil (up to 28.45) and murrum (up to 8.03). The composite TS94RBI6 showed maximum gain. Optimum quantities of CaO, Al_2O_3, and SiO_2 react among themselves and show high strength value. It is clear that the increase in CBR value is directly proportional curing period and percentage of RBI.

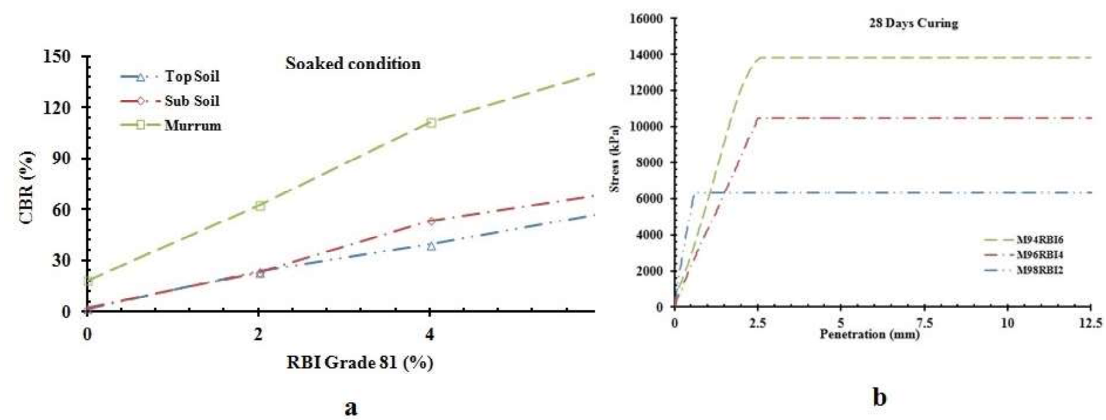

Figure 3: a CBR values of treated and untreated material in soaked condition. b Plots between stress and penetration for murrum + RBI after 28 days of curing

Table 5: California Bearing Ratio Values of composites

Composites	CBR (%)		
	Soaked	7 Days Cured	28 Days Cured
M100RBI0	18	21.6	24.92
M98RBI2	62.16	81.34	91.68
M96RBI4	111.16	139.18	152.08
M94RBI6	140.66	183.81	200.12
SS100RBI0	2.1	2.73	3.1
SS98RBI2	23.16	29.39	32.74
SS96RBI4	53.5	56.27	63.67
SS94RBI6	68.65	80.2	88.2
TS100RBI0	1.7	2.2	2.33
TS98RBI2	23.5	27.18	31.7
TS96RBI4	39.33	46.18	53.41
TS94RBI6	57.63	68.76	74.44

UNCONFINED COMPRESSIVE STRENGTH

Samples are prepared at OMC and MDD obtained from modified proctor compaction test as the haul roads are compacted with compactors and sprinkled with water to avoid dust generation at regular interval. Except few samples, most failed samples exhibited shear type failure. Singh and Ghosh (2006) interpreted that such failure reflects the combined effect of sample and machine. The UCS value of murrum, sub-soil, and top-soil are 663.4 kPa, 71.3 kPa, and 56.2 kPa, respectively, in uncured condition, which is very less and classify these material inadequate as pavement material as reported by Das (1994). **Table 6** shows the strength properties of composite after curing period. It is found that UCS increases with the increase of RBI percentage. The strength gained by murrum with 2 to 6% RBI is highest compared to other developed composites. The UCS gain varies between 2.07 and 21.94 for all composites cured for 28 days. The developed composites showed augmented strength values with an increase in RBI percentage and curing period as shown in **Figure 4**. Sivapullaiah and Jha (2014) mentioned that strength gain is based on the optimum presence of CaO, Al_2O_3, and SiO_2, and the strength gain will stopped further even with addition of these minerals.

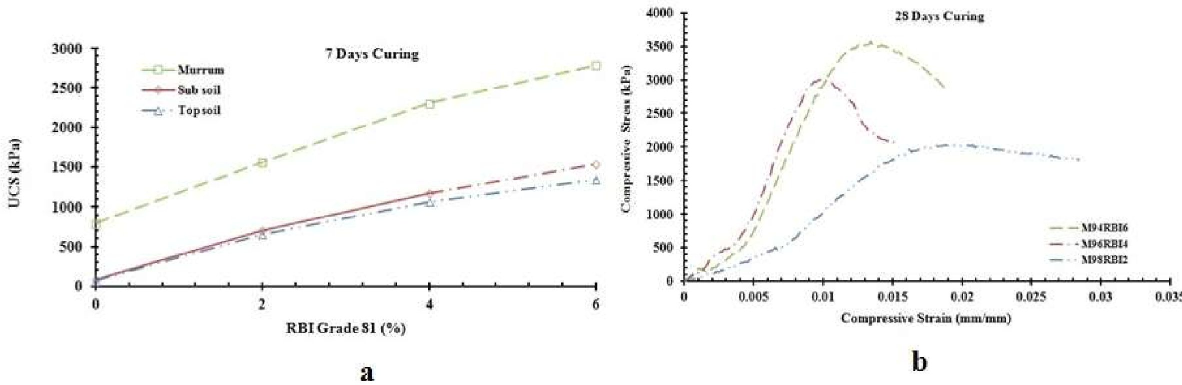

Figure 4: a UCS values of treated and untreated material after 7 days of curing. b Plots between axial stress and axial strain for murrum + RBI after 28 days of curing

Table 6: Unconfined compressive strength values of composites

Composites	UCS (kPa)		
	7 Days Cured	14 Days Cured	28 Days Cured
M100RBI0	796.6	871	987
M98RBI2	1566	1868	2047
M96RBI4	2310	2780	3055
M94RBI6	2790	3354	3685
SS100RBI0	85.56	94.4	106.5
SS98RBI2	703	849	931
SS96RBI4	1169	1410.3	1547
SS94RBI6	1538	1856	2031
TS100RBI0	67.44	74.7	82.4
TS98RBI2	654	794	856
TS96RBI4	1067	1293.27	1427
TS94RBI6	1346	1640.6	1808

SCANNING ELECTRON MICROSCOPY

Figure 5 shows the surface morphology of M94RBI6, SS94RBI6, and TS94RBI6 cured for 28 days. The surface morphology of these composites shows the formation of cementitious gel and ettringite rods due to the pozzolanic reaction between ingredients. It is reflected by gain in elastic and strength properties determined during laboratory tests.

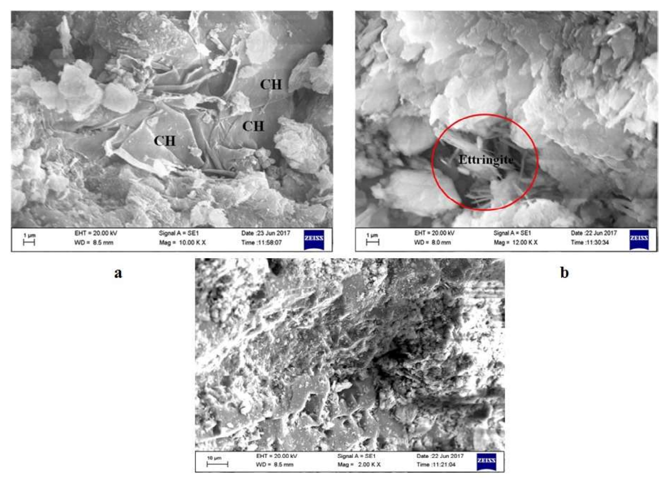

Figure 5: Surface morphology of a M94RBI6, b SS94RBI6, and c TS94RBI6

COMPARISON WITH OTHER DEVELOPED COMPOSITES

The CBR values of the composite developed in the current study are comparable with earlier composites developed by Tannant and Kumar (2000), Cetin et al. (2010), Behera and Mishra (2012), and Mallick and Mishra (2017). Cetin et al. (2010) carried out laboratory test on unpaved road surface material, fly ash, and lime kiln dust. The CBR values of the unpaved road material stabilized with 10–20%of fly ash and 2.5–5% of lime kiln dust were between

69 and 142% at 7-day of curing and 164% at 28-day curing as shown in **Figure 6**. Behera and Mishra (2012) carried out investigation on mine overburden and fly ash treated with 2 to 6% lime. It is found that UCS was 2 MPa for 20% fly ash and 80% mine overburden treated with 6% lime after 28 days of curing, whereas the CBR for 15% fly ash and 85% mine overburden was around 160%. Mallick and Mishra (2017) investigated mine overburden and fly ash treated with 2 to 8% clinker. It is found that UCS was 1.4 MPa for 62%fly ash and 30%mine overburden treated with 8% clinker after 28 days of curing. Similarly, CBR for 62% fly ash and 30% overburden treated with 8% clinker after 28 days of curing was 140%. Tannant and Kumar (2000) carried out investigation on mine spoil (waste dump), coal seam partings, and fly ash treated with 3.5 to 30% kiln dust. Mixtures of fly ash (16– 25%) with mine spoil or coal partings (70–80%) and kiln dust (2.5–5%) produced strength values of 0.4–0.6 MPa and 0.8– 1.0 MPa at 7 and 28 days of curing, respectively. Similar trend was observed while determining the UCS value for 70% coal parting, 30% kiln dust, and 70% mine spoil and 30% kiln dust as shown in **Figure 7**. Comparison with the previous studies shows that the strength gain due to addition of RBI as a stabilizer is more effective as compared with the lime kiln dust, lime, and clinker as stabilizers.

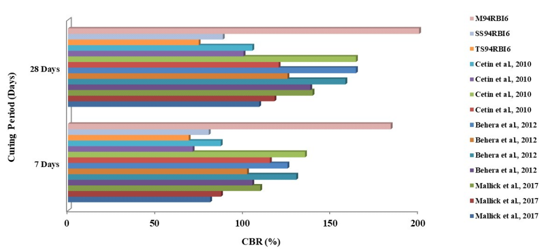

Figure 6: Comparison of CBR values of developed composites

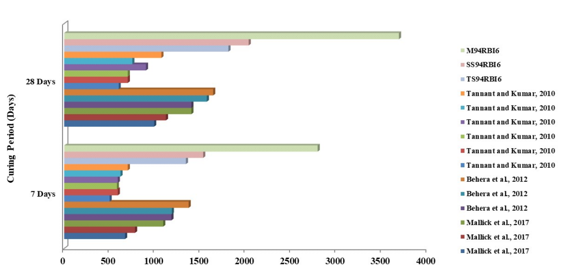

Figure 7: Comparison of UCS values of developed composites

CONCLUSIONS

In the current study, performance of three overburden materials are evaluated after stabilized with 2–6% of RBI. Earlier researchers have used the waste dump material which is mixture of all the overburden materials. The following inferences are drawn from current investigation.

1. Maximum dry density of all composites decreased with increase in RBI percentage. This decrease in MDD can be attributed to the replacement of soil with lightweight admixtures. A decrease in MDD due to the flocculation is due to interaction between the particles and its groups.
2. Liquid limit and plasticity index decreased whereas plastic limit increased with the increase in RBI percentage. This is because of reduction in thickness of double diffuse layer due to increase in electrolyte concentration of pore fluid.
3. Based on CBR value, untreated murrum alone is suitable for pavement. But after treatment, all composites of murrum, sub-soil, and top-soil are suitable for use in pavement.
4. The mechanical properties like CBR, UCS of composite increase with the RBI percentage. The composite M94RBI6 (94% murrum and 6% RBI) showed highest strength values among all developed composites. Curing period for these composites played a significant role in strength enhancement. Addition of 6% RBI increases the CBR and UCS values of murrum, subsoil, and top-soil significantly.
5. All composites showed increased strength due to formation of cementitious gel. Surface morphology confirmed the formation of hydrated gel and ettringite rods due to pozzolanic reaction.
6. Comparative study revealed that the strength gain due to addition of RBI is more effective as compared to lime kiln dust, kiln dust, lime, and clinker.

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An Overview of the Lower Gondwana Coal Resources of Talcher Coalfield, Odisha, India

Pankajini Pradhan* Debashish Das* Shreerup Goswami*

ABSTRACT

The Talcher Coalfield, located in Odisha, India, is an integral part of the Son-Mahanadi Master Basin, spanning over 1,800 sq. km. This coalfield serves as the type area for the Talchir Formation and encompasses both Lower and Upper Gondwana rock sequences. Talcher holds approximately 25% of India's non-coking coal reserves, exclusively in the Karharbari and Barakar formations. Systematic geological studies have revealed distinct structural, depositional, and petrographic characteristics of the Talcher coal seams. The coalfield's geographic and geological features, such as a northwest-plunging synclinal structure, fault systems, and alternating fluvial and paralic depositional environments, contribute to its unique coal properties. The coal seams, distributed across 30 exploration blocks, exhibit variations in quality and composition, influenced by their depositional environments and geological history.

The Karharbari Formation is characterized by low ash content and high-quality coal with bright vitrain, reflecting peat formation in a raised swamp environment under temperate and humid climatic conditions. The maceral composition includes high vitrinite, moderate inertinite, and low liptinite, indicating organic preservation under fluctuating anaerobic conditions. Gymnospermous vegetation, primarily from Glossopteridales and Cordaitales contributed significantly to the formation of these coals. Thick coal seams were deposited in poorly drained, subsiding back swamps with limited terrigenous material, interrupted by an alluvial fan-building event marking the end of Karharbari peat formation. In contrast, the Barakar Formation, with its heterolithic carbonaceous shale and interbedded coal seams, reflects deposition in poorly drained, flood-prone backswamps.

Talcher coals are non-coking and exhibit dull appearances with high moisture and medium to high volatile content. Petrological analyses reveal similarities with the coals of the Satpura and Godavari valley basins, distinguished by the absence of igneous intrusions common in Damodar valley coalfields. Microlithotype studies show the dominance of vitrite, clarite, vitrinertite, and inertite, with notable differences between Karharbari and Barakar coals. Mineral matter, attributed to a drift origin, is finely dispersed within durite and intermediates, complicating beneficiation. However, targeted cleaning of mineral-rich layers offers the potential for grade enhancement.

Trace element analyses highlight variability in the elemental composition between formations. Barakar coals are enriched in Zn, Cd, Na, K, and Pb, while Karharbari coals contain higher Mn, Cr, Fe, Cu, Ni, and Co concentrations. Leaching studies suggest the association of trace elements like Ni, Pb, and Cd with soluble oxides and sulfides, while elements like chromium integrate into organic matrices or occur as insoluble oxides. The combustion of Talcher coals leads to the vaporization of organically bound elements, which subsequently condense with fly ash minerals.

Environmental conditions, including wet moor formation, periodic flooding, and forest fires, played crucial roles in determining the petrographic and chemical properties of the Talcher coals. Evidence of forested mire deposition, high gymnosperm contribution, and alternating oxic to anoxic conditions is reflected in the preserved fusain, vitrain, and miospores. These coals are high in mineral matter presenting challenges in traditional cleaning methods. Despite these limitations, blending Talcher coals with higher-quality coking coals has been proposed for metallurgical applications. Overall, the geological, petrographic, and trace element characteristics make Talcher coals a vital resource for understanding Gondwana coal formation and utilization strategies.

Keywords: Lower Gondwana Coal, Talcher Coalfield, Coal seams, Petrographic characteristics

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INTRODUCTION

The Talcher Coalfield is located in the state of Odisha, India, in the southeastern portion of the Son-Mahanadi Master Basin, which consists of both Lower and Upper Gondwana rock sequences. Spanning more than 1,800 sq. km, it is situated in the Dhenkanal and Angul districts, with smaller areas reaching into the neighbouring Sambalpur and Deogarh districts. The Brahmani River flows along the northern and eastern parts of the coalfield. The geographic extent of this basin ranges between latitudes 20° 49' 19" and 21° 15' 05" N and longitudes 84° 19' 56" and 85° 31' 21" E (Figure 1). Being the type area for the Talchir Formation of the Lower Gondwana Group, the Talcher Coalfield holds a significant place in the Gondwanas of India.

The presence of coal in this basin was first reported by T. Oldham in 1837 (Oldham, 1856), and the initial systematic survey was conducted during 1855–56 by Blanford et al. (1856). Several studies have been conducted on the geology, structure, and coal seams of the basin, including those by Fox (1934), Pascoe (1959), Subramanian (1971), Pareek (1963), Das and Rath (1974), Raja Rao (1982), Manjrekar et al. (2006), Singh (2016a, b), Mohanty & Parui (2020), Nanda et al. (2022), Chakraborty et al. (2022) and others.

GEOLOGY

The Talcher Basin features a northwest-plunging synclinal structure, with its eastern end forming the closure and progressively younger rock layers appearing as outcrops towards the west. Hence, the Lower Gondwana rocks are exposed in the eastern part, while the Upper Gondwana rocks are exposed in the westernmost part. The strata dip gently to the north, where the number of coal seams also increases, hinting at a potential homoclinal arrangement. Steeper inclinations of bedding planes occur in the vicinity of fault zones. The general strike of the sedimentary layers aligns roughly E–W, although this orientation can vary locally, from ENE–WSW to ESE–WNW. To the north, the Precambrian-Permian boundary is defined by a set of faults trending WNW–ESE, while the southern boundary is characterized by an exposed unconformity without significant faulting. Three primary fault systems are present within the basin, oriented along E–W, NE–SW, and WNW–ESE trends (Raja Rao, 1982; Manjrekar et al., 2006). The basement of the Talcher Coalfield consists of Precambrian rocks, unconformably overlain by the Talchir Formation, followed by the Karharbari, Barakar, Barren Measures, and Kamthi formations (Table 1).

The rocks of this coalfield are believed to be of fluvial origin (Bhattacharya et al., 2002), although evidence of marine influence has been identified from various locations across different formations based on the presence of acritarchs, ichnofossils, coarse-grained sandstones, wave ripples, and phosphate salts (Goswami, 2008). These marine footprints indicate a coastal marine to deltaic (paralic) mode of origin of the coal beds and associated sediments in the Talcher Coalfield (De, 2001, Goswami, 2002, 2008).

COAL SEAMS

Gondwana rocks host over 99% of the country's coal reserves, and Talcher Coalfield hosts about 25% of the non-cocking coal reserves of India. The coal seams in the Talcher Coalfield are typically non-coking and confined only to the Karharbari (Sakmarian-early Artinskian) and Barakar (late Artinskian-Kungurian) formations. A total of 11 coal seams are reported to date from this coalfield, of which Seam I is from the Karharbari Formation and the remaining seams (Seam II to XI) are from the Barakar Formation (Table 2). The coal seams are not uniformly formed across the coalfield. Karharbari coals are found in split sections and is most prominently developed in the eastern part of the basin, with some occurrences in the central and northern regions. Barakar coals are best developed in the eastern, central, and northern parts of the coalfield. However, all the coal seams (Seam I to XI) are developed in the Osouth-central part (Kosala and Kosala East) area. As of April 2019, the estimated coal reserve of India was 3,26,495.63 million tonnes, of which the Gondwana coalfields accounted for 3,24,871.98 million tonnes. Odisha holds 80.84 billion tonnes, ranking second to Jharkhand (84.50 billion tonnes), out of which 51.22 billion tonnes of coal are estimated from the Talcher Coalfield (Chakraborty et al., 2022).

COAL CHARACTERISTICS

The coal from the Talcher Coalfield exhibits distinct characteristics that reflect its geological origins and depositional environments. The Karharbari Formation is known for its high-quality coal with Ash+Moisture content ranging between 16% and 29%, contrary to the Barakar Formation with Ash+Moisture content ranging between 30% and 55% (Table 2) (Chakraborty et al., 2022).

Rank analysis based on volatile matter (daf) and vitrinite reflectance (Ro) shows that Karharbari coals, with lower volatile matter and higher vitrinite reflectance, are classified as high volatile ‘C’ to ‘B’ bituminous, whereas Barakar coals range from sub-bituminous ‘A’ to high volatile ‘C’ bituminous (Panda et al., 2022; Singh, 2016a, b). Lithologically, the Talcher coals primarily comprise vitrain and clarain. Banded bright coal occurs in both formations, more prominently in Karharbari, whereas banded dull coal and dull coal are confined to the Barakar Formation (Singh, 2016a, b).

Microlithotype analysis identifies vitrite, clarite, vitrinertite, and inertite as dominant components, with negligible amounts of liptite and clarodurite. The Karharbari Formation exhibits higher vitrinite and lower liptinite content compared to Barakar, though inertinite concentrations remain similar. Karharbari coals also have higher combined vitrinite and liptinite content, while Barakar coals contain more mineral matter (Singh, 2016a, b).

Suitability of Talcher coal for combustion is supported by its low ash fusibility, as indicated by heat treatment studies that reveal the formation of phases like hematite, rutile, mullite, and aluminium phosphate ($AlPO_4$) at 1000°C (Banerjee et al., 2016). FTIR (Fourier Transform Infrared) studies highlight the predominance of oxygen-bearing functional groups, primarily acidic hydroxyl and carboxyl groups, which are significant in controlling mineral matter and ash content. The similar absorption patterns of durain and clarain with bulk samples suggest these lithotypes largely influence the bulk characteristics of the coal (Mishra et al., 1998).

In comparison to other Indian coalfields, Talcher coal is non-coking, has a dull appearance, and is high in moisture and medium to high in volatile content. It differs from the Raniganj Coalfield in its lack of distinctly banded durain and from the Jharia and Giridih Coalfields, which are richer in vitrite, clarite, and fusite. The coals of the Ib-river Coalfield, though resembling Talcher coals, have significantly higher mineral matter content (Navale and Srivastava, 1969; Subramanian, 1971). Blending Talcher coals with higher-quality coking coals has been suggested to enhance coke strength for metallurgical applications (Pareek, 1963).

The high mineral matter content in Talcher coals, typical of Gondwana coals, is attributed to their drift origin. During deposition, inorganic material was transported along with organic detritus, leading to its fine dispersion within the coal matrix. This drift origin explains the intimate mixing of mineral matter with organic components, particularly within “intermediates” and durite layers (Pareek, 1963).
Trace element studies of Talcher coals reveal notable differences between the Barakar and Karharbari formations. The Barakar Formation contains higher concentrations of Zn, Cd, Na, K, and Pb, while the Karharbari Formation is richer in Mn, Cr, Fe, Cu, Ni, Co, Ca, and Mg. Notably, Sn was undetectable in any coal seam (Senapaty and Behera, 2012).

Leaching studies indicate that trace elements such as Ni, Co, Pb, and Cd are primarily associated with soluble oxides and sulphide minerals in coal. Chromium is partly integrated into the organic matrix and also occurs as insoluble oxide phases, such as chromite, whereas manganese is likely linked to organic matter. Elements associated with organic compounds or pyrite tend to vaporize during combustion, subsequently reacting with minerals in fly ash to form condensed compounds (Mohanty et al., 2001).

COAL DEPOSITION

The coal seams of both the Karharbari and Barakar formations in the Talcher basin were formed under temperate to mildly warm, humid climatic conditions that supported rapid vegetation growth and high plant diversity. The Karharbari coal seams, characterized by low ash content, suggest peat formation in a raised swamp environment with limited terrigenous input. This initial phase of peat accumulation was abruptly ended by a significant alluvial fan-building event. The Barakar Formation, on the other hand, features thicker coal seams, often interbanded with sandstone, shale, and siltstone, indicating prolonged peat formation in slowly subsiding, poorly drained environments. Over time, as the climate became more favourable, plant diversity increased, leading to the formation of extensive, thick coal seams in both formations (Chakraborty et al., 2022).

The maceral composition of Talcher coals, dominated by high vitrinite, moderate inertinite, and low liptinite, suggests organic matter preservation predominantly under anaerobic conditions with fluctuating water levels. Peat formation was primarily derived from C_3 vascular land plants in a telmatic environment with forested vegetation, reflecting excellent preservation of woody tissues (Panda et al., 2022). Microscopic evidence, including the preserved cell structures of vitrinite, fusinite, and durain, suggests a gymnospermous origin, likely from Cordaitales and Glossopteridales. Gymnosperms, along with miospore-producing plants such as *Parasaccites* and bisaccate forms, contributed significantly to the organic detritus in the peat. The durain, composed of fibrous material, monosaccate miospores (e.g., *Parasaccites*), and woody elements like vitrinite and fusinite, reflects contributions from these plants. These coals, characterized by impurity, and high moisture content, are indicative of a forested mire origin with extensive fusinization (Goswami et al., 2006, 2008; Goswami and Singh, 2013; Navale, 1965).

The depositional environment of Talcher coals alternated between wet moors and periods of moderate to high flooding, with water table fluctuations influencing the petrographic and chemical properties of the coal. Peat accumulation occurred under varying oxic to anoxic conditions, leading to good preservation of plant tissues. Forest fires during the coal formation period are suggested by the abundant fusain fragments and lenticles observed in the coal seams (Singh, 2016a, b; Navale, 1965).

Petrological characteristics show that Talcher coals resemble those of the Satpura and Godavari valley basins but differ from Damodar valley coals due to the absence of igneous sills and dikes, indicating less volcanic influence in Gondwana basins south of the Damodar valley (Pareek, 1963). The coals from Nandira and South-Balanda area are particularly notable for their microfragmental nature, with durain as the dominant lithotype (Navale, 1965).

The finely dispersed mineral matter, present as microscopic grains in durite and intermediates, makes it difficult to reduce its proportion using traditional cleaning methods. These mineral-rich layers, along with shaly coal, significantly influence the coal's quality. However, the beneficiation of these bands offers a potential pathway for improving the grade of Talcher coals (Pareek, 1963).

CONCLUSION

The Talcher Coalfield, situated in the southeastern part of the Son-Mahanadi Master Basin in Odisha, holds a pivotal position in India's Gondwana coal reserves. With over 51 billion tonnes of coal, it constitutes a significant portion of India's non-coking coal reserves, crucial for the country's energy needs. The geological and depositional history of the coalfield reveals a complex interplay of structural, climatic, and biological factors that influenced coal formation, quality, and characteristics.

The Talcher coals were primarily deposited in a fluvial-dominated environment with episodes of marine influence, evidenced by sedimentary features and fossil assemblages. The coal seams are associated with the Karharbari and Barakar formations, each reflecting distinct depositional settings. Karharbari coals, formed in raised swamp environments, exhibit low ash content, high vitrinite, and excellent preservation of woody tissues, indicative of anaerobic conditions. Barakar coals, deposited in poorly drained back-swamps, display heterolithic layering, higher mineral matter, and greater variability in petrographic and chemical properties.

The mineral matter content in Talcher coals, typical of Lower Gondwana coals, is attributed to their drift origin. Inorganic materials were transported alongside organic detritus, becoming finely dispersed within the coal matrix. This mineral matter, primarily embedded in durite and intermediates, poses challenges for coal cleaning and upgrading but can be managed through beneficiation. Petrological comparisons indicate similarities with coals from the Satpura and Godavari basins but distinguish Talcher coals from those of the Damodar Valley due to differences in volcanic influence.

Trace element studies highlight the distinct geochemical signatures of the Karharbari and Barakar formations, with elements like Zn, Cd, Pb, and Na enriched in the Barakar coals, while Mn, Cr, Fe, and Ni are more prevalent in the Karharbari coals. Leaching studies reveal that elements associated with oxides and sulphides are prone to release during combustion, forming condensed compounds in fly ash.

The depositional conditions of Talcher coals—alternating between wet moors and periodic flooding—coupled with varying oxic to anoxic environments, facilitated the preservation of plant tissues, primarily gymnosperms. This is corroborated by the presence of vitrinite and fusinite with gymnospermous cell structures. Forest fires during coal formation, suggested by fusain fragments, also contributed to the distinctive features of the coal.

In conclusion, the Talcher Coalfield represents a dynamic geological archive, showcasing the interplay of depositional processes, mineralogy, and vegetation. Its significance extends beyond its reserves, providing insights into Gondwana coal formation and offering opportunities for future resource management and utilization through beneficiation and innovative combustion strategies.

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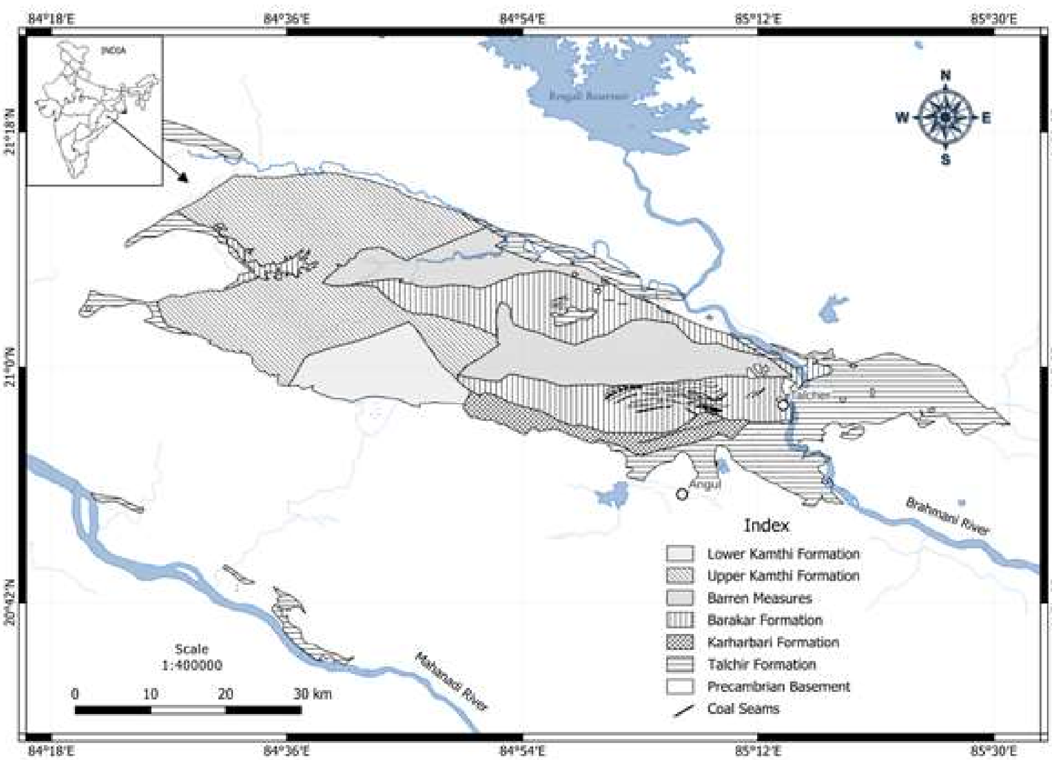

Fig. 1. Geological map of Talcher Basin showing the investigated fossil locality (after Raja Rao, 1982; Manjrekar et al., 2006; Goswami & Singh, 2013; Geological Survey of India, Govt. of India, 2021).

Table 1. Stratigraphic nomenclature of Talcher Basin, Odisha (after Raja Rao, 1982; Manjrekar et al., 2006; Singh, et al., 2006; Goswami et al., 2006, 2007; Saxena et al., 2014; Chakraborty et al., 2022).

Age		Fomation		Lithology	Thickness (in metre)
Recent		---		Alluvium and laterite	
Late Triassic	Anisian	Upper Kamthi	Upper Bed	Ferruginous, hard and quartzitic sandstones, bands of compact brown, grey, and yellow shales and clasts of lavender and creamy white shales.	500-550
Early Triassic			Lower Bed	Medium-grained, cross-bedded ferruginous yellowish white sandstones, alternating with thick bands of red and grey shales.	
Late Permian	Lopingian	Lower Kamthi		Medium to coarse grained, pebbly cross-bedded ferruginous sandstones, clasts of greenish-white and greyish white shales, pink clays.	
------------------------------Depositional hiatus------------------------------					
Middle Permian	Guadalupian	Barren Measures		Coarse to medium-grained greenish grey feldspathic sandstones with shreds and lenses of chocolate coloured clay, micaceous siltstone, dark grey shale, carbonaceous shale, purple brown shale, and clay ironstone.	125-200
Early Permian	Asselian-Sakmarian	Barakar		Fine to coarse-grained feldspathic whitish sandstones, siltstone, grey shale, sandy shale, fireclay, and coal seams with polymictic conglomerate at the base.	180-350
	Sakmarian-Artinskian	Karharbari		Medium to coarse-grained whitish arkosic sandstones, carbonaceous shale, grey shale, and coal seams.	200-275
	Artinskian-Kungurian	Talchir		Diamictites, rhythmites, turbidites, conglomerate, fine to medium grained greenish sandstones, olive coloured needle shales, turbidite, tiliets, and tilloids.	325+
--Unconformity--					
Precambrian				Granites, gneisses, amphibolites, migmatites, quartzite, and pegmatites	

Table 1. Coal seams of Talcher Coalfield (after Raja Rao, 1982; Chakraborty et al., 2022).

Formation	Coal Seam	Thickness (m)	Ash + Moisture (%)	Grade
Barakar	XI	6-17	35-55	E-G
	X			
	IX			
	VIII	5-44	35-55	E-G
	VII			
	VI			
	V	2.5-33	35-52	E-G
	IV			
	III top	14-48	30-45	D-F
	III middle			
	III bottom			
	II top	<1-19	35-55	D-G
	II bottom			
Karharbari	I	1-17	16-29	

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Solving Key Mining Industry Challenges with AI Solutions

Presented by: COGNECTO

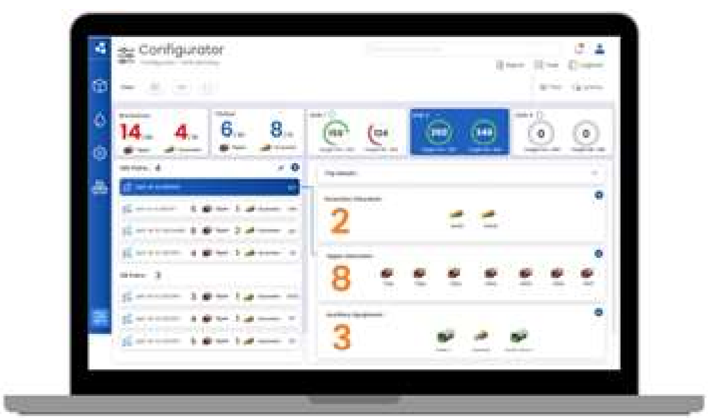
The mining industry grapples with operational inefficiencies, asset mismanagement, and delays in reporting, further compounded by increasing demands for resource optimization and safety compliance. Cognecto platform leverages IoT, real-time monitoring, and data analytics to streamline operations and solve these challenges comprehensively.

GEOFENCING:ENSURING BOUNDARY COMPLIANCE

Challenges: Unauthorized vehicle movements and inefficiencies in asset tracking beyond designated zones.

Solutions:

- **Static and Dynamic Geofences**: Configurable boundaries updated in real time based on operational data.
- **RFID Integration**: Logs machine interactions (e.g., excavator-tipper pairings) with precise timestamps.
- **Alarm Triggers**: Notifications for unauthorized zone entries or boundary breaches.



• Planning Assets & Target

PRODUCTION MONITORING AND HAUL CYCLE OPTIMIZATION

Challenges: Manual trip sheet logging leads to data inaccuracy and inefficiencies in cycle time analysis.

Metrics:

- 60% reduction in unauthorized movements.
- Off-road dumping reduced to <5%.

SHIFT PLANNING: OPTIMIZING RESOURCE ALLOCATION

Challenges: Delays due to manual shift planning and underutilization of resources.

Solutions:

- **Dynamic Operator Roster**: Real-time availability of operators linked to rostered shifts.
- **Cross-Functional Synchronization**: Enables workshops and production teams to align on machine readiness.
- **Multiple Material Handling**: Supports loaders managing different materials simultaneously.

Metrics:

- Shift preparation time reduced by 50%.
- 20% improvement in asset utilization.

• Analysing Loading & Dumping

Solutions:

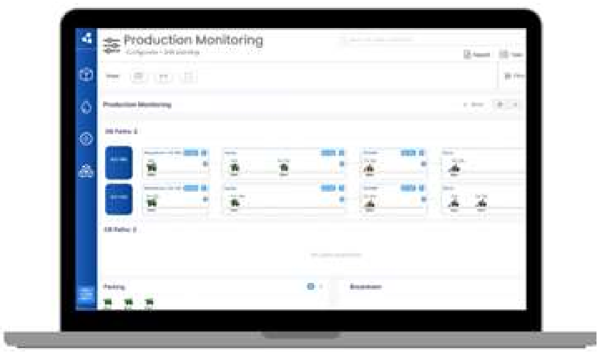
- **IoT Sensors**: Capture BCM, tonnage, and travel times for each haul truck cycle.
- **Automated Haul Cycle Monitoring**: Tracks each stage, from loading to dumping, with precise timestamps.
- **Overloading Alerts**: Prevents haul trucks from

exceeding capacity, ensuring compliance and safety.

Metrics:
- Haul cycle times reduced by 15%.
- Overloading incidents decreased by 40%.

MAP VISUALIZATION FOR OPERATIONAL INSIGHTS

Challenges: Supervisors lack actionable visibility into equipment and material flows.



- Insights on Cycle Time

AUTOMATED REPORTING AND COMPLIANCE MANAGEMENT

Challenges: Manual data reconciliation and delays in reporting undermine decision-making.

Solutions:
- **Automated Dashboards**: On-demand performance reports with customizable parameters.
- **System Compliance Alerts**: Flags equipment operating outside predefined parameters, ensuring real-time corrective actions.

Metrics:
- Reporting accuracy increased to 99%.
- 85% reduction in report generation time.

CONCLUSION

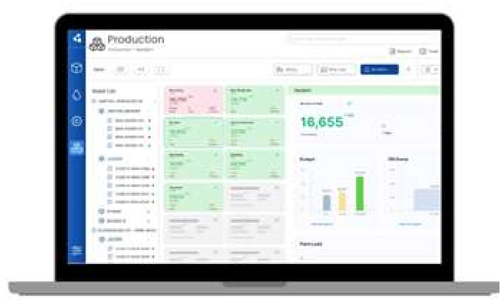
By addressing challenges such as manual inefficiencies, delayed reporting, and equipment mismanagement, our digital solutions empower mining operations with actionable insights and operational control. The integration of geofencing, shift planning, automated reporting, and real-time monitoring enhances productivity while ensuring safety and compliance.

Solutions:
- **Real-Time Dashboard**: Geographical view of equipment locations and operational zones.
- **Route Optimization**: Identifies and mitigates delays in hauling operations.

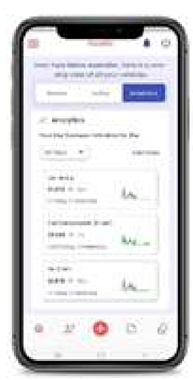
Metrics:
- Fuel efficiency improved by 10%.
- 75% faster stoppage resolution.

- Heat Map for Operations

With these innovations, mining companies can achieve sustainable growth, cost savings, and operational excellence.



- MIS for Reporting



- Production Trend

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Evaluation of Sustainable Reclamation of Coalmine Land in Odisha - A Case Study

Mukteswar Pradhan* Singam Jayanthu** D S Nimaje**

ABSTRACT

Odisha is one of India's leading coal-producing states and plays a crucial role in meeting the country's power needs. However, coal extraction can cause environmental challenges like soil erosion, loss of biodiversity, and water pollution. In response, coal mine operators have implemented several reclamation efforts to address these issues and restore ecological balance. These efforts include land restoration, reforestation with native species, water treatment, and improving soil fertility.

One key challenge in reclamation is the management of topsoil. When topsoil is stockpiled for later use in rehabilitation, its quality and quantity can decline over time. Issues like compaction, nutrient loss, and the reduction of microorganisms and organic matter are common. This paper examines the factors causing this loss of topsoil quality and suggests possible improvements in its management during mining operations.

The study concludes that the best approach for topsoil management is to strip and immediately replace fresh, dry topsoil. Additionally, continuous monitoring, independent environmental control, and offering financial incentives to contractors may help preserve topsoil. This paper also reviews current strategies for managing topsoil in open-cast coal mines, based on existing research, case studies, and best practices. It looks at the environmental impacts of coal mining on soil and ecosystems, highlighting the importance of effective topsoil management to reduce these impacts. The review considers factors like geological conditions, climate, vegetation, and regulations that affect topsoil management. Research has shown that topsoil stockpiles lose essential nutrients like organic carbon, nitrogen, potassium, and phosphorus, particularly in the first year after stockpiling.

Keywords- sustainable mining, reclamation, topsoil, rehabilitation, nutrient leaching, stockpiling

INTRODUCTION

Opencast coal mining, while essential for meeting global energy demands, poses significant environmental challenges, particularly concerning soil management. The extraction process necessitates the removal of overlying soil layers, disrupting natural ecosystems and leading to the loss of valuable topsoil. In response, translocated topsoil practices have emerged as a critical strategy to mitigate the environmental impact of mining operations and facilitate land reclamation. However, the effective management of translocated topsoil remains a complex and multifaceted endeavor, requiring careful planning, implementation, and monitoring. This paper aims to provide a comprehensive review of current practices and strategies for managing translocated topsoil in opencast coal mines. By synthesizing existing literature, case studies, and best practices, this review seeks to elucidate the challenges and opportunities associated with topsoil management and identify areas for further research and improvement. The importance of preserving soil quality and fertility cannot be overstated, as topsoil serves as the foundation for terrestrial ecosystems and agricultural productivity. Consequently, translocated topsoil practices must be successfully implemented in order to ensure the long-term viability of affected landscapes as well as to lessen the environmental impact of coal mining. This review will examine a number of topics related to topsoil management in open-pit coal mines, such as methods for removing, moving, and reclaiming topsoil and the function of vegetation in stabilizing soils that have been translocated. It will also look at how well the mining industry's present regulatory frameworks and mitigating measures function to resolve issues with soil. Ultimately, this study seeks to educate policymakers, industry stakeholders, and researchers on the most recent advancements and developing trends in the area by summarizing and critically assessing the body of knowledge on topsoil management in opencast coal mines. This synthesis is intended to help promote

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sustainable mining methods and protect soil resources in coal mining sites across the globe. The assessment assesses current methods for topsoil extraction, transportation, storage, and reclamation in open-pit coal mines by drawing on best practices. The analysis also evaluates how policy interventions and regulatory frameworks influence topsoil management techniques and promote environmentally friendly mining methods. Critical analysis of the drawbacks and restrictions of present topsoil management techniques reveals areas in need of further study and development.

As most of the coal seam is found at shallow depths, over 93% of the coal mined has come from surface mining techniques. Though it is a very inexpensive process, surface mining can lead to a number of environmental issues, including deforestation, land degradation, and the loss of regional biodiversity. Deforestation and land degradation are unavoidable since the majority of coal resources are found in river basins and forests, both in India and beyond. In addition, surface mining causes the development of several land uses that are relatively less profitable than the original land use, as well as overburden (OB) dumps, mines, voids, and water bodies (Ahirwal and Maiti, 2016). Large stretches of desolate terrain are created as a result of coal mining, which needs a sizable area to extract the coal seam from the earth. Mining operations in a certain location run day and night with significant levels of noise, which disrupts the neighbouring society and reduces biodiversity (Singh, 2017). Mine subsidence, which is occasionally brought on by underground mining, is another major worry for society. Runoff from coal stocks and mining regions that is extremely acidic has the potential to contaminate groundwater and harm human health. Moreover, the release of dangerous gasses into the atmosphere is another way that underground coal mine fires, both in India and elsewhere, harm the environment. There is a desire to rehabilitate mine-degraded land and mitigate the environmental repercussions of mining due to the cumulative impact of mining activities that has alarmed scientific communities and stockholders worldwide. The depth of soil layers, the amount of silt, sand, and clay, the ability to store water, the rate of infiltration, the compatibility of the soil when it is stacked, the erodibility, and the amounts of N, P, and K are among the several features of soil.

The review concludes by offering recommendations for enhancing topsoil management in opencast coal mines, emphasizing the importance of stakeholder collaboration, technological innovation, and adaptive management approaches. By synthesizing and critically evaluating existing knowledge, this review aims to inform policymakers, industry stakeholders, and researchers about the latest developments and emerging trends in topsoil management, ultimately contributing to the advancement of sustainable mining practices and environmental stewardship in coal mining regions worldwide.

LITERATURE REVIEW

Surface mining methods are widely used to excavate coal and their efficiency greatly depends on the depth of a given coal seam. This method can recover up to 90% of the coal found on the upper surface. Large-scale surface mining of coal requires huge areas and mining equipment, such as shovels, dumpers, draglines, and conveyors. During surface mining, the entire vegetation cover is removed, and the soil and subsoil are scraped out and stored separately. A typical view of an excavated area showing the topsoil, subsoil, and coal seam in a forest area. The removal of Overburden (OB) materials exposes the coal seam which will be fractured and mined out using mining machinery. Until the entire coal seam is mined out, all the OB materials are dumped outside the query area, generally known as external dumping. Once these dumps are inactive, they are stabilized through benching, regrading of spoil piles, and topsoil blanketing (Ahirwal et al., 2016). The design of an external dump is another important aspect of technical reclamation, which includes the periodic study of the slope to measure slope angle and stability.

TOPSOIL MANAGEMENT

Topsoil refers to the uppermost layer of the earth's crust that sustains plant development, acts as a habitat for microfauna, and recycles nutrients from the soil. Dark in colour and rich in nutrients and organic materials, topsoil generally has a rich texture. The topsoil is a good environment for the growth of flora and fauna because it facilitates the development of roots and other significant biological activities. (Miyawaki, 2004)Topsoil promotes the growth of intermediary processes and vegetation cover (Ferreira and Vieira, 2017). Organic matter is broken down by microfauna in topsoil, which then mineralizes to liberate bound nutrients. Topsoil improves mine spoils' general

Table 1: Important findings of few research work and report reviewed

Year	Author	Title	Important findings
2001	Ghosh M	Management of topsoil for geo-environmental reclamation of coal mining areas.	Different aspects of topsoil stripping and stockpile designing
2016	Ahirwal and Maiti	Assessment of soil properties of different land uses generated due to surface coal mining activities in tropical Sal (Shorea robusta) forest,	Overburden and topsoil quality of different aged mine dumps
2021	Mineral Conservation & Development(Ammendment) Rules		Regulatory framework for topsoil management
2004	Haering et al.	Appalachian mine soil morphology and properties	Changes in soil properties after removal and stockpiling.
2017	Liu et al.	Changes in soil properties in the soil profile after mining and reclamation in an opencast coal mine on the Loess Plateau, China.	Preservation topsoil quality and erosion control measures.

fertility quality, infiltration qualities, and soil structure. In order to restore microbial life at a specific post-mining site, topsoiling is necessary since it provides nutrients and ideal physical conditions for microbial development. Some general things to think about when controlling topsoil in mining regions. According to Maiti et al. (2015), the management of topsoil in mining sites includes inventory preparation, scraping and preservation, redistribution on post-mine land, and soil characterization throughout the entire process. To enable successful mine rehabilitation, a Topsoil Management Plan (TMP) must be created that outlines how topsoil will be maintained in a form that is as close to its pre-mining condition as feasible. When clearing topsoil in advance of mining operations, the TMP must be used. The TMP outlines protocols for topsoil storage for the duration of the updated Project as well as suitable topsoil use for progressive pit closure and rehabilitation. The TMP makes available the following data:

a) Description of the existing soil within the mine site.
b) Topsoil stripping procedure that aims to maximize volumes of suitable topsoil removed thereby maximizing topsoil available for mine closure and rehabilitation works.
c) Stockpile design and maintenance procedure.
d) Erosion control techniques – for stockpiled topsoil and exposed subsoil following stripping and during mine rehabilitation.
e) Topsoil application procedure – to be used during mine rehabilitation; and
f) Reporting and reviewing requirements.

Topsoil Inventory

A detailed soil survey is required to be carried out to assist with the identification of suitable topsoil material to salvage. Thus, site-specific characteristics of topsoil which influence soil stripping, stockpiling, and redistribution should be recorded. The following activities are followed.

a) Preparation of a topsoil map: The preparation of a topsoil map includes an indication of areas to be affected and not to be affected by mining operations and the depth of topsoil and subsoil (stripping depth) on a scale of 1:4000.
b) The description of a mapping unit: This describes the similarities or dissimilarities of topsoil in terms of characteristics and depth of suitable topsoil.

c) Soil sampling: Sampling locations should be clearly marked. The sampling analysis of major soil horizons and organic layers should be separately described. Generally, a soil profile should be sampled from up to
d) 1.5 m or bedrock. Even below the 1.5 m depth, it is suspected that soil is suitable for reclamation.
e) Soil analysis: The soil sample should be placed in a clean polythene bag, labeled properly, and taken to a laboratory and should be analyzed using standard test methods.
f) Data presentation: The presentation of the data should be scientific and clear.
g) describe the results of the analysis,
h) mapping unit, location of the area, and soil horizon.
i) Topsoil stripping: It is recommended that as part of the mining plan, the guideline should outline the process of salvaging the topsoil. The plan should include: the delineating procedure for the removal of topsoil, the training of equipment operators to handle the topsoil, and the monitoring of the process of salvaging the topsoil by an expert.
j) Volumetric presentation: The data should represent the total amount of topsoil and its partition in the salvaged and available topsoil for reclamation.

Topsoil removal

The removal of topsoil from mining areas leads to the disruption of soil aggregates, inter-mixing of soil layers, and the destruction of the matrix between the soil flora and fauna. According to the MCDR (2017), topsoil has to be mined separately and preserved for reclamation purpose. Topsoiling includes the trans- location of soil from a mining site to a stockpiling site, which also transfers organic matter, substrates, micro-fauna, and seeds that potentially enrich the fertility of the soil. It is advisable that the extent of disturbance should always be kept to a minimum. Topsoil should only be removed from those areas which were formally disturbed by mining or associated activities. Soils of 10—15 cm stripping depth are common, but depth may vary with the site. Topsoil stripping is necessary wherever land is planned to be disturbed by mining activities to recover the soil resource for rehabilitation purposes. Topsoil stripping will be undertaken in areas of planned mining activity including the coal preparation and handling plant, the active pit areas, out-of-pit dumps, haul roads, hardstands, access roads and other general infrastructure (e.g. dams). Initially stockpiling of topsoil will be necessary until the out-of-pit dumps are constructed and in-pit backfilling of spoil has advanced enough to allow rehabilitation activities to safely commence behind the active mine path. As the mine pits expand, there will be more opportunity to strip topsoil and apply it directly to re-contoured areas, thus avoiding topsoil stockpiling. Freshly stripped and placed topsoil retains more viable seed, micro-organisms and nutrients than stockpiled soil. Vegetation establishment is generally improved by the direct return of topsoil and is considered ‘best practice’ topsoil management. Suitable topsoil will be stripped for use in the rehabilitation program. The topsoil will either be stockpiled until suitable re-contoured areas are available, or preferably be directly returned immediately across the areas to be rehabilitated. Topsoil material resource assessments will be carried out in advance of mining to confirm the accuracy of the pre-mine topsoil survey data. These assessments may include:

a) topsoil depth confirmation.
b) possible additional chemical analysis to confirm suitability (pH, EC, Cl-, CEC and Cations), particularly around soil type boundaries or where variation is suspected in relation to the original soil survey.
c) dispersion characteristics for erosion potential; and
d) review of existing soils data and experience gained in topsoil recovery of adjacent mining areas.

Topsoil translocation and storage

The height of stockpiles should be kept as low as possible (preferably within 2 m or less) with a large surface area. Higher height leads to the formation of an anaerobic zone and all soil properties may be lost because of anaerobe conditions. A typical view of the topsoil dumps and schematic presentation of a topsoil dump is shown in Figure 1. The followings points are considered during stockpiling.

1. Location of stockpiling: While selecting the place to stockpile the soil, slopes, natural drainage pathways, and traffic routes should be avoided. Topsoil should be stored over a large area near the place where it will be reused.
2. Sediment barriers: The use of sediment fences should be encouraged to avoid runoff of sediments from the topsoil dump.
3. Temporarily seeding the stockpiles should be done wherever possible to protect the fertility of the topsoil. A grass—legume mixture could be used as a fast-

growing cover species as well as to retain the quality of the topsoil. A permanent covering should be applied to the vegetation to retain the fertility of the stockpiles which were not reused within 12 months. The sowing of a grass—legume mixture along with seeds of small shrubs at the periphery of the stockpiles is preferable.

Stockpile design

Designing of topsoil stockpile is most vital to consider during project planning to accommodate the desired quantities of overburden removal. The objective of proper stockpile design is to conserve topsoil in a condition as close as possible to its original state and minimise soil loss or erosion.

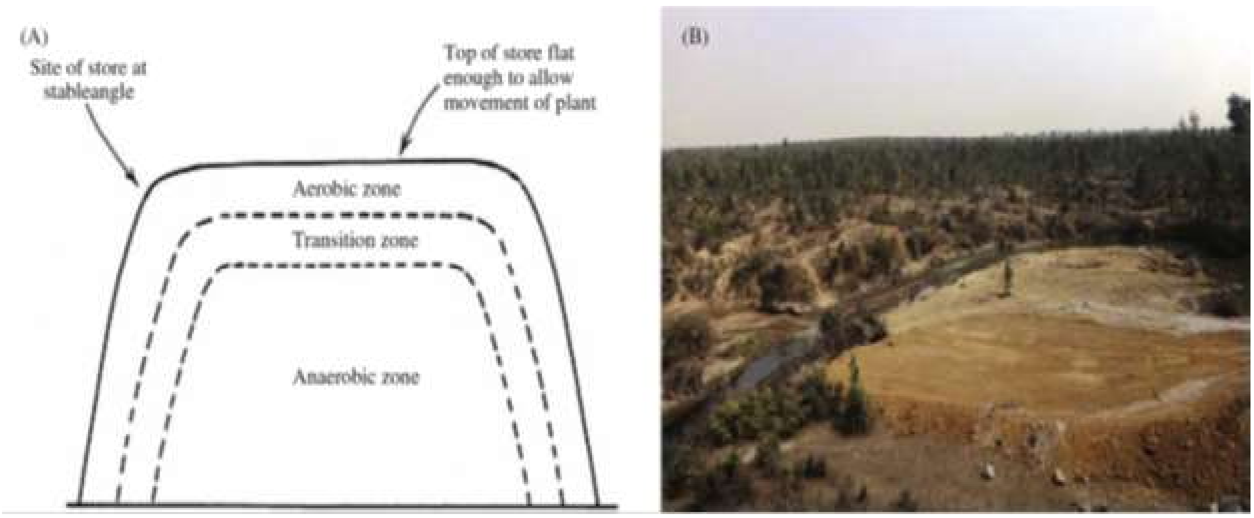

Figure 1 - (A) Schematic lay out of topsoil storage; and (B) original view of the topsoil dump in an open cast coal mining project, India. (after Ahirwal and Maiti, 2016)

Stockpile locations are selected subject to the following management actions.

a) Least movement of machinery and vehicles
b) Overland water flow onto or across stockpile site will be kept to a practical minimum.
c) Where possible, stockpile sites will be selected to maximise protection from ‘the prevailing winds, particularly if the material is friable in nature (e.g. sand or silt). Establishing stockpiles within a buffer treed zone or in the lee of hills, may be appropriate for these circumstances.
d) All long-term topsoil material stockpiles will be located outside the active mine path and away from drainage lines.
e) Drainage from higher areas will be diverted around stockpile areas to prevent erosion.
f) As required, sediment controls will be installed downstream of stockpile areas to collect any run-off.
g) Topsoil stockpile locations will be strategically located to assist the sequence of future rehabilitation.
h) Separate stockpiles for topsoil and subsoil will be formed in low mounds of minimum height. (3 m maximum) and maximum flat surface area, consistent with the storage area available.

   Stockpiling using a greater number of low (<2 m high) mounds, rather than a few high spoil type dumps, is preferable. Long term stockpiles will be revegetated to minimise loss of soil quality. Revegetating stockpiles will minimise weed infestation, maintain soil organic matter. levels, maintain soil structure and microbial activity and maximise the vegetative cover of the stockpile.
i) The strength of typical topsoil after compaction may be around 6000 kPa, whereas root growth is restricted at 3000 kPa. Therefore, care should be taken that compact should not exceed 1400 kPa (Hanks and Lewandowski, 2003).

Stockpile Erosion Management

Stockpiles to be retained for a period greater than six months will be sown with a cover crop if a natural vegetative cover does not establish. Topsoil stockpiles will be clearly signposted for easy identification and to avoid any inadvertent losses. The establishment of declared plants on the stockpiles will also be monitored and control programs implemented as required.

Stockpile designs are to have a 1:3 (V:H) batter gradient. Stockpiled material is to be clear of surface water drainage lines and vegetated areas and freshly harvested topsoil is likely to develop vegetation cover without supplementary seeding (Booth, 2016). However, where natural regeneration of vegetation is inadequate in topsoil stockpiles or subsoil stockpiles, then stockpiles will be sown with a seed mix representing the original vegetation community. Irrigation may be desirable to get rapid protection from cover. Sowing desirable vegetation will also assist with outcompeting weed species. While stockpiles are in a bare condition, they are to be sprayed with an erosion control product with a cover rating C-factor of 0.05 or less.

Impact on Properties of topsoil

Relocated topsoil often experiences compaction and loss of porosity due to mechanical disturbances during extraction, transportation, and reclamation processes. This compaction reduces water infiltration rates and soil aeration, impacting plant root growth and overall soil structure. Relocation can lead to changes in soil pH, nutrient availability, and organic matter content. Soil pH may fluctuate due to exposure to different environmental conditions or mixing with underlying substrates. Additionally, nutrient levels may be altered, with potential losses of essential elements such as nitrogen, phosphorus, and potassium. Organic matter content may decrease due to oxidation or decomposition during handling and storage.

Mine soils are often pedogenically young soils that have been derived from the mixtures of fragmented and pulverized rock material (Miao et al., ; Ussiri and Lal, 2005). Mine soil that develops on post-mining sites is initially characterized by high rock fractions (40%—60%), low water holding capacity (10%—20%), high bulk density (1.5 Mg m^{-3}), highly acidic or alkaline pH, and low infiltration rate (0.2—0.5 cmh^{-1}) (Maiti, 2007; Ahirwal and Maiti, 2016). Mine soils are nutrient deficient, particularly those associated with fertility, such as nitrogen (N), phosphorus (P), potassium (K), and they have low soil organic matter (SOM) (Sencindiver and Ammons, 2000; Haering et al., 2004). Sometimes, a low pH is reported in mine soils in some areas possibly due to the presence of sulfur-bearing pyrites (FeS_2) in OB layers. Selected mine soil properties of revegetated coal mine soil in India are summarized in Table 2. Soil provides a suitable medium and substrate for plants to expand their roots, as well as adequate water and nutrients to grow.

However, plant establishment and growth on mine spoils are often limited due to physical factors rather than chemical imbalances. Important physical properties of soil, which are known to affect plant growth on mine spoils include, a coarse fraction, texture, bulk density, moisture, and rooting depth. Biochemical properties of mine soil such as pH, electrical conductivity, organic matter, macro- and micronutrients, and concentrations of toxic chemicals or heavy metals are also important to consider for plant growth. Soil Physiochemical and Biochemical Properties of the mineoils in various coal in India are presented in table 2 (Ahirwal and Maiti, 2016).

TABLE 2: Soil Physiochemical and Biochemical Properties of the Young Revegetated Coal Mine Soils in India (Ahirwal and Maiti, 2016).

	Study Area				
	BCCL[a]	CCL[b]	MCL[c]	ECL[d]	SCCL
	(4 years)	(5 years)	(5 years)	(5 years)	(5 years)
Soil Properties	(0—10 cm)	(0—10 cm)	(0—20 cm)	(0—15 cm)	(0—20 cm)
Sand (%)	74.0 6 0.4	75.6 6 2.1	65.33	70.9 6 2.1	NA
Silt (%)	20.0 6 0.1	13.6 6 0.8	9.31	20.1 6 2.2	NA
Clay (%)	6.0 6 0.1	10.6 6 0.6	25.53	11.6 6 0.9	NA
Bulk density (Mg m^{23})	1.12 6 0.05	1.51 6 0.08	1.34	1.44 6 0.2	1.29 6 0.1
Moisture (%)	4.66 6 1.0	4.96 6 1.0	7.55	NA	NA
pH (1:2.5; w/v)	7.2 6 0.4	4.9 6 0.08	5.62	8.2 6 0.01	6.7 6 0.2
EC (dS m^{21}) (1:2.5; w/v)	0.18 6 0.06	0.13 6 0.02	0.46	0.06 6 0.002	0.12 6 0.01
SOC %	1.83 6 0.4	1.15 6 0.05	0.42	1.20 6 0.01	0.37 6 0.01
Av. N (mg kg^{21})	94.5 6 11.4	50.7 6 6.1	21.05	54.6 6 3.6	67.8 6 4.35
Av. P (mg kg^{21})	2.45 6 0.6	10.9 6 0.9	2.95	4.0 6 0.5	0.51 6 0.10
Ex. K (cmol kg^{21})	NA	0.08 6 0.01	0.03	0.17 6 0.01	NA
CEC (cmol kg^{21})	NA	10.5 6 0.9	8.82	9.20 6 0.06	NA

The loss of organic carbon, available nitrogen, potassium and phosphorous as well as microbial population in trans-located topsoil dumps has been documented by Ghose (2001), which found the greatest loss of these to occur during the first year after stockpiling (typically 30%, and in many cased 50% after 3 years of stockpiling) followed by a flattening of the loss curve. A generalised curve for these losses is presented in Figure 1.

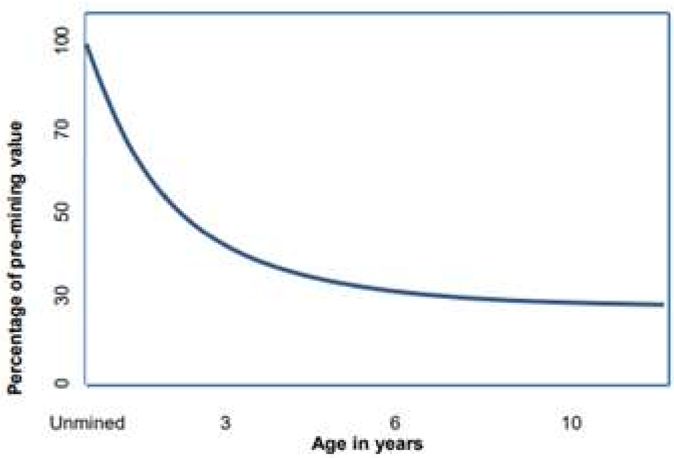

Figure 1 - Generalized loss curve of available N, P, K and organic carbon in stockpiled soil against unmined soil over time (after Ghose, 2001).

The loss of the viable mycorrhizae and seedbank has been analyzed and documented by Leu et al. (2012). Accordingly, seeds that germinate on the stockpile do not aid the rehabilitation process due to their not completing their lifecycle and producing more seeds for rehabilitation time. Suicidal germination, where seeds germinate too deeply and then die off, or surface germination where seeds germinate and then die when spreading takes place are some of the reasons for loss of the seedbank. Figure 1 - generalized loss curve of available N, P, K and organic carbon in stockpiled soil against unmined soil over time (after Ghose, 2001). Due to this early loss of soil quality, various sources of research and accepted best practice indicates immediate placement as the ideal situation. A problem for this ideal approach is the availability of receiving areas. A possible solution is to use the soil from one operational area in a mining complex to another. Although this is not always possible for the exact area that soils were extracted from, it is generally so that a typical coal complex in the Highveld will have various opencast pits, and various areas requiring rehabilitation within its mine right area. The immediate placement of topsoil is therefore realistic in some instances. In cases where this is not possible, concurrent rehabilitation should be seen as second best and rehabilitation only after the operations phase as bad practice. The geometry and height of topsoil heaps based on soil type the slope of topsoil heaps should ideally be 1:3 or 18.5° in order to maximize the aerobic zone surface, and prevent excessive erosion. This appears as a rudimentary approach and is not supported by clear evidence. Further, the maximum height of topsoil stockpiles should also be determined per type of soil, with 5.0 m height proposed as maximum for sandy soil and 1.0 m as a maximum for heavy clayey soil (Ghose 2001). The reason for this is the weight and related compaction potential of the different types of soil. Moreover, the placement of topsoil heaps in individual loads separately from each other would yield a higher surface area exposed to the atmosphere, and therefore normal soil processes. The challenge with stockpile location is often available space and the impact of soil stockpiles on the natural area in question – the covering of a predominantly natural area with soil means that the biophysical process of the area in question would be impacted, in essence exacerbating the impact of soil impacts. Dry vs. Wet stripping Soil stripping in conditions with especially >10% moisture content leads to compaction in the topsoil stockpile. (Lima et al. 2016). This phenomenon has been observed by others as well (Cristescu, 2012) and can be accepted as a fact.

CONCLUSION

The past decade across the world has witnessed initiatives for improvement of policy and operational front to address the challenge of land degradation by introducing effective management of topsoil. From a sustainable development perspective, these mechanisms piloted in some countries offers a significant learning for adaptation. Further, as per the findings and analysis, proper management of topsoil can be highly supportive for fur repurposing of mine degraded land. It is evident that effective topsoil management is essential for mitigating the environmental impacts of coal mining and facilitating the successful reclamation of mined lands. Techniques such as topsoil extraction, transportation, and reclamation play crucial roles in preserving soil fertility, promoting vegetation growth, and restoring ecosystem functions. While significant progress has been made in developing and implementing topsoil management practices, challenges remain. Geological constraints, climatic variability, and regulatory compliance pose significant obstacles to the sustainable management of translocated topsoil. Addressing these challenges will require innovative approaches, stakeholder collaboration, and adaptive management strategies. Moving forward, it is imperative for policymakers, industry stakeholders, and researchers to work collaboratively to address the identified challenges and implement solutions that prioritize environmental conservation and land rehabilitation. By embracing technological innovation, stakeholder engagement, and best practices, the mining industry can enhance its contribution to sustainable development and ensure the long-term health and resilience of ecosystems affected by coal mining activities.

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Small Scale Mining of Limestone & Sustainable Development

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ABSTRACT

Sustainable development is an important component of any mining activities. This has enabled the mining industry to formulate systems, adopt technologies in respect of the the communities living in and around mining areas, organisations handling statutory aspects for sfater-conservation and environment. So far globally and in Indian perspective this aspect of sustainable development, Sustainable Development Goals of UNDP etc have become an integral part of mining operations for large mines. There are thousands of other mines falling in the category of small scale and artisanal are also contributing over 40 to 50% of the production of major minerals like limestone, manganes, dolomiute, building stones, etc. These mines are having land area of few hectares to as high as hundred hectres depending on the lease conditions and government norms. An attempt has been made in this paper to highlight the role of small scale mines and their sudstainable development status with special reference to limestone.

INTRODUCTION

The mining sector serves as a fundamental pillar of the Indian economy, occupying a vital position within the resource supply chain. The extraction and processing of minerals possess immense potential to fuel a substantial share of the nation's economic growth, acting as a catalyst for overall development. However, the sector's role differs significantly across countries and remains inadequately documented and underutilized, preventing it from achieving its maximum potential. It is a well-established fact that some of the world's most impoverished, vulnerable, and least developed nations are heavily dependent on mineral resources, often struggling to translate their natural wealth into sustainable progress.

SMALL SCALE MINING

Small-scale mining refers to the extraction of minerals using basic, cost-effective techniques, often incorporating limited mechanization, such as excavators and dredgers. Typically managed by individuals or small groups, it serves as a crucial source of livelihood, particularly in developing nations where employment opportunities are scarce. While it contributes significantly to local economies, especially within the informal sector, small-scale mining often operates with minimal regulation. This lack of oversight can result in severe environmental degradation, hazardous working conditions, and heightened safety risks for miners. Despite these challenges, its economic significance remains undeniable, providing income and sustaining communities that rely on mineral resources for their survival.

The classification of mining units into small, medium, and large-scale categories varies across countries, as there is no universally accepted standard. India has a long history of mining, and in the post-independence era, growth in the sector—except for certain public sector enterprises—has primarily been driven by small and medium-sized mining operations (Rudra, 2002). Small-scale mining and quarrying, particularly for industrial minerals and construction materials, are characterized by relatively lower production volumes and a smaller workforce. The maximum production capacity of 50,000 to 100,000 tonnes per annum has been accepted as the criteria for study.

Small-scale mining (SSM) encompasses a range of mining activities that are typically labor-intensive and utilize basic technology. Definitions of small-scale mining vary across countries and organizations, reflecting differences in regulatory frameworks and economic contexts.

The Intergovernmental Forum on Mining defines small-scale mining as operations that can range from informal individual miners earning a subsistence livelihood to more formal and regulated small-scale entities producing minerals commercially.

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The International Institute for Environment and Development (IIED) describes ***'small-scale mining as mining activities conducted by individuals, groups, families, or cooperatives with minimal or no mechanization, often operating in the informal sector'***. According to the Environmental Health Journal, small-scale mining is defined as mining conducted by small companies with limited financial resources and a limited number of miners. Pact, an international development organization, characterizes small-scale mining as a largely informal economic sector that includes workers around the world who use basic tools to extract minerals and other materials.

These definitions highlight that small-scale mining is typically characterized by low levels of mechanization, limited financial resources, and a significant reliance on manual labor. Small-scale mining operations often function informally, outside of formal legal and regulatory frameworks, which can lead to challenges such as environmental degradation, health and safety risks, and socio-economic issues within mining communities.

Small-scale mining mining is generally part of the informal sector, characterized by basic mining techniques, a large workforce, and poverty (OECD, 2016). In small-scale mining, there may be some mechanization in both the mining and beneficiation processes. Small-scale mining, involves mechanization such as excavators, dredgers, and earth-moving equipment, engaging small to medium capacity machineries.

ROLE OF LIMESTONE

Limestone plays a pivotal role in India's economic development, serving as a cornerstone for various industries and contributing significantly to the nation's GDP. As the primary raw material for cement production, limestone supports India's position as the second-largest producer and consumer of cement globally. The cement industry alone accounts for approximately 95% of the country's total limestone consumption, underscoring its importance in infrastructure development and construction.

In addition to its critical role in cement manufacturing, limestone is integral to the steel industry, where it is used as a flux in blast furnaces to remove impurities during iron extraction. The mineral's utility extends to the production of lime, which is essential in various chemical processes, environmental applications, and the manufacturing of paper, glass, and plastics.

Despite being endowed with substantial limestone reserves, India has emerged as the world's largest importer of limestone, with imports valued at approximately [1] 5,900 crore in 2023. This reliance on imports highlights the growing domestic demand driven by rapid urbanization, industrialization, and infrastructure projects.

The economic impact of limestone mining and processing is multifaceted. It generates employment opportunities, stimulates local economies, and contributes to the development of ancillary industries. However, it is imperative to address environmental concerns associated with limestone extraction, such as deforestation, habitat destruction, and pollution, to ensure sustainable development.

Mishra and Pradhan(2024) delve into these aspects, examining the balance between harnessing limestone's economic potential and implementing environmentally responsible practices. Their analysis provides insights into policy measures and technological innovations aimed at optimizing limestone utilization while mitigating ecological impacts. Limestone is indispensable to India's economic growth, underpinning key industries and infrastructure projects. Strategic management of this vital resource, coupled with sustainable practices, is essential to maximize its benefits and minimize environmental repercussions.

LIMESTONE MINING SCENARIO OF INDIA (FIGURE 1)

Limestone is a naturally formed mineral, primarily composed of calcium carbonate (Oates 2008). It forms commonly in shallow, calm and warm marine waters, as found in the Caribbean Sea, the Indian Ocean, the Persian Gulf and the Gulf of Mexico (King 2005). Another way of limestone that forms is through evaporation, with this type of limestone growing in caves around the world (Critchfield 2017).

Figure 1 : Limestone Map of India

The production of limestone (Table 1 & 2) in 2021-22 at 393 million tonnes increased by about 12.50% as compared to that of the previous year. There were 689 reporting mines in 2021-22 as against 665 during the previous year. Thirty six mines, each producing more than 3 million tonnes per annum contributed 47 percent of the total production of limestone in 2021-22. The share of 21 mines, each in the production range of 2 to 3 million tonnes was 13% of the total production. 20% of the total production was contributed by 54 mines, each producing 1 to 2 million tonnes annually. The remaining 20% of the total production was reported by 578 mines and 7 associated mines during the year. Ten principal producers contributed about 54% of the total production. About 2.47% of the production. About 2.87% of the production was reported by Public Sector mines as against 2.48% in the previous year. About 97% of the total production of limestone during 2021-22 was of Cement grade and remaining 3% by other grades. Table 1, explains distribution of Mining Leases of India :

Table 1 : Area wise Distribution of Mining Leases* (Frequency in Hect.) (Other than Atomic, Hydro Carbons Energy & Minor Minerals) As on 31.03.2023 (P) (All India)(By States)

Frequency Group Area in Hects.	Number of Mining Leases	Percentage of total leases	Area in "000 Hects.	Percentage of total area
0 to 2	**368**	**12**	**477.95**	
> 2 to 5	**809**	**27**	**3135.74**	1
> 5 to 10	**353**	**12**	**2594.36**	1
>10 to 20	**319**	**11**	**4661.15**	2
>20 to 50	388	13	12680.12	4
>50 to 100	231	7	16707.48	6
>100 to 200	182	6	26016.43	9
>200 to 500	197	7	64146.87	23
Above 500	160	5	151936.44	54
Total	3007	100	282356.54	100

Table 2: Limestone production trend of India during the year 2018-19 to 2023-24 (A) (Source: https://mines.gov.in/webportal/content/production-2024)

Mineral: Limestone		Unit: tonnes
Year	**Quantity**	**Value**
2018-19	3,79,975,000	8,95,84,489
2019-20	3,59,464,000	8,88,90,081
2020-21	3,49,120,000	8,64,84,125
2021-22	392,034,000	102,022,623
2022-23	405,552,000	110,880,666
2023-24	450,456,000	118,547,400

Rajasthan was the leading producing State accounting for (22%) of the total production of limestone, followed by Madhya Pradesh and Andhra Pradesh (13%), Chhattisgarh (11%), Karnataka (10%), Telangana (7%) , Tamil Nadu (5%), Gujarat (6%) and the remaining 13% was contributed by Assam, Bihar, Himachal Pradesh, Jammu & Kashmir, Jharkhand, Kerala, Maharashtra, Meghalaya, Odisha and Uttar Pradesh.

Mine-head closing stocks of limestone for the year 2020-21 was 24.19 million tonnes and for the year 2021-22 is 27.24 million tonnes. Average daily labour employment in limestone mines in 2021-22 was 19,464 as against 20,470 in the previous year.

PRODUCTION TRENDS OF LIMESTONE IN INDIA (TABLE 3)

India's limestone production has seen a significant upward trend in recent years, with notable growth recorded in FY 2024. The country produced 407 million metric tons (MMT) of limestone between April 2023 and February 2024, marking an 11.2% increase compared to the previous year. Limestone plays a crucial role in key sectors like cement, steel production, and infrastructure development. It is expected that production will continue to rise, with a forecast of around 450 MMT in FY 2024-25. As one of the top global producers, India is ranked third in limestone production.

Table – 3: Production of Limestone 2019 – 20 to 2021 – 22 (By States)Qty in '000 tonnes; Value in ¹ 000')

State	2019 – 20		2020 – 21		2021 – 22*	
	Quantity	Value	Quantity	Value	Quantity	Value
India	359464	88890081	349120	86484948	392760	97349550
Andhra Pradesh	42532	9267248	41148	8685149	50260	10444417
Assam	1552	500950	1552	469810	1681	537696
Bihar	556	263446	1000	301961	987	367151
Chhattisgarh	42669	10200663	40378	10139974	41888	11009962
Gujarat	22868	5204303	22227	5080904	23543	4959400
Himachal Pradesh	12527	2746801	12018	2618878	13710	2966412
Jammu & Kashmir	959	280284	1175	300656	1156	354825
Jharkhand	785	339164	324	233245	72	35005
Karnataka	34165	6672035	33188	6095069	39405	7611350
Kerala	398	342144	376	331191	379	345424
Madhya Pradesh	**47118**	**12332360**	**46099**	**12879609**	**50140**	**14782552**
Maharashtra	14614	3475512	13943	3476065	15757	3869717
Meghalaya	7248	2988280	6029	2689713	6399	2872708
Odisha	5627	1848621	7186	2118507	7059	2410646
Rajasthan	72390	19094468	74266	19449722	87679	22220563
Tamil Nadu	24461	7151088	21144	5813723	21334	6265788
Telangana	26161	5249950	24493	4904676	28502	5620487
Uttar Pradesh	2804	932764	2574	896096	2809	675447

LIMESTONE MINING BY SMALLSCALE OPERATIONS AND SUSTAINABLE DEVELOPMENT

Limestone had a significant role in meeting limestone demand of user industries, local area development, employment generation, poverty alleviation as per 17 SDG goals etc.

The Indian limestone market generated a revenue of approximately ¹ 26,900 crore in 2023 and is expected to reach around ¹ 48,700 crore by 2030, growing at a CAGR of 8.8% from 2024 to 2030.

Limestone plays a vital role in the paper industry, primarily in the form of calcium carbonate (CaCOƒ), which serves as a filler material and coating pigment to enhance the brightness, opacity, smoothness, and printability of paper while reducing production costs. Ground calcium carbonate (GCC) is used as a filler, whereas precipitated calcium carbonate (PCC) is used in coatings for high-end printing and magazine papers. Additionally, calcium carbonate helps maintain the alkalinity of paper, preventing acid-related degradation and improving durability. Its use reduces the need for acidic chemicals, making the paper production process more environmentally friendly by lowering energy consumption and emissions.

The demand for paper in India is experiencing robust growth, with an annual increase of approximately 6-7%, positioning the country as one of the fastest-growing paper markets globally. This surge is largely attributed to the expansion of educational institutions and the packaging industry. The packaging paper and paperboard segment, in particular, is projected to grow at a compound annual growth rate (CAGR) of 8.2%. Concurrently, the consumption of limestone in the food and beverage, as well as pharmaceutical industries, is expected to rise, driven by increasing demand for high-purity limestone in these sectors. These trends collectively indicate a significant and ongoing increase in limestone consumption within the country.

The small-scale limestone mining faces several challenges, including regulatory hurdles, environmental concerns, and limited access to advanced technology. Addressing these issues will contribute to the long-term sustainability and economic growth of the sector.

MINING POLICIES

The Mines and Minerals (Development and Regulation) (MMD&R) Act of 1957 is the main legal framework governing the mines besides the Indian Mines Act of 1952 which is primarily meant for labour welfare and safety and health issues. The Central Government has empowered the respective State Governments to frame their own rules in the case of minor minerals under section 15 (1) of M.M. (D&R) Act, 1957.

Sustainable Development Goals explained in Figure 2 :

Figure 2 : Sustainable Development Goals (SDGs) in Small-Scale Mining in India

Small-scale mining (SSM) in India plays a crucial role in supporting economic development, particularly in rural and mineral-rich regions. However, for this sector to align with the **United Nations Sustainable Development Goals (SDGs)**, it must address environmental sustainability, social equity, and economic viability. Achieving sustainability in SSM involves balancing mineral extraction with responsible resource management, worker welfare, and community development.

Key Areas of SDG Contributions in Small-Scale Mining
1. Economic Development (SDG 1: No Poverty, SDG 8: Decent Work and Economic Growth)

- **Employment Generation:** SSM provides livelihood opportunities, particularly to marginalized and low-income groups.
- **Entrepreneurship & Local Economy:** Promotes mineral-based small businesses, value addition, and local economic growth.
- **Income Stability:** Ensuring fair wages, social security benefits, and financial inclusion for miners.

2. Environmental Sustainability (SDG 13: Climate Action, SDG 14: Life Below Water, SDG 15: Life on Land)

- **Sustainable Extraction Practices:** Encouraging water conservation, responsible mineral processing, and minimal environmental footprint.
- **Habitat Protection:** Reducing land degradation, preventing deforestation, and restoring mined-out areas.
- **Pollution Control:** Implementing clean technology to mitigate air, soil, and water contamination.

3. Social Well-being and Inclusivity (SDG 1: No Poverty, SDG 3: Good Health and Well-being, SDG 5: Gender Equality, SDG 10: Reduced Inequalities)

- **Worker Safety & Fair Labor Practices:** Implementing workplace safety measures, protective gear, and regulated working hours.
- **Community Engagement:** Ensuring local participation in decision-making, consent-based mining operations, and fair compensation.
- **Healthcare & Education:** Investing in medical facilities, schools, and skill development programs in mining regions.
- **Gender Empowerment:** Encouraging women's participation in skilled mining jobs and leadership roles.

ROLE OF NEW TECHNOLOGIES FOR SUSTAINABLE MINING

Small scale mines face closure and an uncertain future due to slow and difficulty in access to 'new technologies' like use of instruments for devising safe methods in blasting, slope stability and other areas so as to maintain production. Chakravorty, S.L.(2001) brought out various aspects of small scale mining and suggested remedial measures to improve upon their workings for maintaining balance between the resources, environment and the people working and living in and around the mines.

Mishra & Pradhan(2024) had extensively detailed the limestone mining scenario of India and highlighted the role of small scale mines which account for 21% production fron 561 mines. IBM(2023) had also enumerated the production trend and technologies adoipted in small and largescale mines in India.

Water resources are reported of getting deteriorated on receiving pollutants from open dumping of mining waste, quarries and other anthropogenic activities (Ekmekçi, 1993; Younger, 2002; Mahananda et al., 2010; Phiri et al., 2005; Rim- Rukeh et al., 2009; Caruso et al., 2011). Mining in many areas have resulted in depletion and degradation of natural resources including water resources and the effects is severe in terms of its quantity and quality. Change in quality of water were detected by monitoring its various physical, chemical and biological parameters (Sargaonkar and Deshpande, 2003; Duran and Suicmez, 2007; Venkatesharaju et al., 2010).

Kumar et al. (2016) made a study on Application of remote sensing to assess environmental impact of limestone mining in the Ariyalur district of Tamilnadu.

Pujari and Soni (2008) presented a paper on Sea water intrusion studies near Kovaya limestone mine, Saurashtra coast, India.

Dhatrak et al. (2014) carried out a study on Health status evaluation of small scale limestone mine workers of Rajasthan to determine the morbidity pattern among workers engaged actively in mining activities. Findings of the study showed poor literacy rate amongst the miners. Lung function test showed restrictive impairment in about 15% of miners. Hypertension, diabetes and musculoskeletal morbidity were prevalent in miners. The study findings indicate the need for regular health checkups, health education, personal protective devices and engineering control for better health and productivity of the miners.

Mishra et al. (2004) presented a case study on Environmental pollution status as a result of limestone and dolomite mining in the small town of Biramitrapur, situated in the Sundargarh district of Orissa.

CONCLUSION

The role of small scale mines vis-à-vis sustainable development has been highlighted. It has revealed that unlike the large mines, small scale mines have large labour force working in a manual to semi-mechanised operations. For the overall improvement of sustainable development of the local areas and labour force much emphasis is needed.

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