

THE INDIAN MINING & ENGINEERING JOURNAL

(Incorporating Mineral Markets: The Founder Publisher & Editor: J.F. De. Souza, Mumbai)

VOLUME 63: No.05-06

MAY-JUNE 2024

ISSN 0019-5944

(PEER REVIEWED JOURNAL DEVOTED TO MINING, EARTH SCIENCES & ENGINEERING)

Contents Technical Papers

03. Indexical Methods Assessing PTEs Distribution in Mahan River Command Area, Central India's Coal Mining Zone
Nirmal Kumar & Prof Mahendra Kumar Tiwari
14. Backfilling in Opencast Mines Using Red Mud - An Indian Case Study
Aditya Jha
31. Assessment of Air Quality and its Effects on Vegetation and Human Health Proximate to J.P. Cement Plant Rewa M.P.
Mahendra Kumar Tiwari, R.M.Mishra & R.S. Parihar
37. Arsenic: Occurrence and Health Hazard
Bhupendra Kumar Mishra
43. Profile Particulate Matter Generated at Higher Depths in Opencast Mines
Sneha Gautam, Basanta Kumar Prusty & Aditya Kumar Patra
52. Sustainable Development Goals vis-à-vis Resource Dimensions of a Mine : An Indian Case Study
Pukhraj Nenival

www.theimejournal.com

Publisher : Anita Pradhan, IME Publications

Editor-in-Chief: Prof. S.Jayanthu,

National Mineral Awardee, Deptt. of Mining, NIT, Rourkela

Mob. 9938303259 , Email: sjayanthu@nitrkl.ac.in

Editor: S.K.Mahanta,

Mob.: 9437002349

Email: sushantamahanta2349@gmail.com



Correspondance Address

The IM & E Journal 1457, Fishery Tank Road, Chintamaniswar, Laxmisagarpatna, Bhubaneswar - 751006, Odisha

Mobile: +919861008387, **Mail:** indianminingjournal61@hotmail.com / indianminingjournal@gmail.com

Branch office: Near TV Tower, JODA, Dt. Keonjhar 758034, Phone: 06767-273173

Associate Editor: A.Sahoo, Mob. 9861008387

The publishers and the editorial team do not necessarily individually or collectively, identify themselves with all the views expressed in this journal.

Papers have been published after due process of scrutiny, editing, corrections and reviewers comments.

EDITORIAL TEAM MEMBERS & REVIEWERS

Technical Editor (Hony.):

Prof. T.N. Singh, National Mineral Awardee,
(Deptt. of Earth Sciences, IIT- Bombay), Director, IIT, Patna
Prof. G. K. Pradhan, National Geoscience Awardee, Prof. of Mining and Dean,
Faculty of Engineering & Technology, AKS University, Satna (M.P) ,
Mob.: 8120003355 Email: gkpradhan58@gmail.com

Principal Consulting Editor:

Prof. Manoj Pradhan, NIT, Raipur
Prof. Khanindra Pathak, National Geoscience Awardee, Deptt. of Mining & Dean,
Indian Institute of Technology - Kharagpur

Consulting Editors:

Dr. D S Rao, CSIR-IMMT
Dr. K.C Brahma, Director, OMC Ltd.
Prof. N.R.Thote, Dept. of Mining, VNIT, Nagpur
Er. V. Srikant, Managing Director, Uttam Blastech, Hyderabad
Dr. M. Ramulu, National Geoscience Awardee, Sr. Principal Scientist, CSIR-CIMFR, Nagpur
Dr. K Ram Chandar, NITK, Surathkal
Dr. B K Mishra, HOD Mining, AKS University, Satna

Overseas Consultants:

Japan: Prof. Hideki Shimada
Nordic Countries : Prof. Uday Kumar, Lulea Technical Univ., Sweden
Thailand: Dr. Thitisak Boonpramote, Asst. Prof., Head of Mining &
Petroleum Engineering Deptt., Chulalongkorn University, Bangkok

Acknowledgement:

The papers published in this volume were also presented at the International Conference on Safe & Sustainable Mining Technologies, IConSSMT 2024 held at AKS University, Satna (M.P) during 19-21 February 2024. The two technical papers, Climate Change - Sustainable Mining and Need for Accelerated Development of Coal by D N Prasad and Rock Fragmentation Research in Mining & Port Construction- Some Applications, by Prof. V.M.S.R. Murthy were the Key Note Papers. Authors who have not attended the Conference, their papers were not published in this volume.

Indexical Methods Assessing PTEs Distribution in Mahan River Command Area, Central India's Coal Mining Zone

Nirmal Kumar* Prof Mahendra Kumar Tiwari**

ABSTRACT

The purpose of this study was to explore PTE contamination and seasonality in different water sources in the coal mining area of the Mahan River command area, Central India. To this end, 96 water samples were collected from various sources of two separate seasons and examined for PTEs. The results show that Mn (18%), Cu (4%), Pb (8%), Ni (18%), Cd (2%), Al (4%), Cr (2%), and Fe (30%), during the pre-monsoon season, and Mn (15%), Pb (6%), Ni (15%), Cd (2%), Al (15%), Fe (46%) and Ba (4%) samples during the post-monsoon surpass the permissible limits. The multiple indexical methods elucidate that 14% (HPI), 14% (HEI), 18% (CI), 14% (EHCI) and 20% (HMI) of samples during the pre-monsoon and at 10% (HPI), 10% (HEI), 15% (CI), 15% (EHCI) and 17% (HMI) samples exceeded standards. The Caboi plot confirms that mine water from Bhatgaon UG, Mahamaya UG, and Mahan OC (PR40, PR41, PR42, PR43, PR47, and PR48), surrounding river, and groundwater resources with the characteristic of "Acid - High Metal" are damaged by acid mine drainage along with mineral dissolution. Apart from the anthropogenic inputs, geogenic and environmental processes are responsible for the current distribution of PTEs and seasonal change.

Keywords: Groundwater, Coal mining, PTEs, Caboi, Multiple indexical methods

INTRODUCTION

Global attention has recently been drawn to major environmental contamination as a result of expanding population and industrialization (Emenike et al., 2019). The indiscriminate disposal of industrial waste in the open environment causes significant environmental degradation (Edokpayi et al., 2017; Kumar et al., 2022). Groundwater is an important component of the environment and the greatest reserve of freshwater available to humans (Singh et al., 2021a). Groundwater has tremendous economic and social worth. However, groundwater supplies are being consumed at an alarming and unsustainable rate in many parts of the world (Singh et al., 2018).

As a result, everyone's primary priorities are sound growth, careful conservation, and constant pollution prevention. India is the world's greatest user of groundwater, consuming an estimated 230 cubic kilometers per year, or almost one-quarter of the global total (Gleeson et al., 2016). According to the NITI Aayog's 2018 report, about 800 million people reside in rural areas, and approximately two lakh people die each year as a result of a lack of

fresh water. Groundwater pollution is often caused primarily by geogenic causes (Wang and Li, 2022). Apart from geogenic pollution, manmade practices play a vital role in groundwater quality deterioration. In this aspect, mining activities such as coal mining can promote severe groundwater as well as surface water pollution (Liang et al., 2017). However, the coal mining activity is of a dual character: on one hand, it is powering the nation and on the other, coal mining and allied industries inadvertently threaten the water environment both in terms of quality and quantity (Panigrahy et al., 2015). Coal, lignite, oil, natural gas, uranium, and water are the main energy inputs for power generation in India (Singh et al., 2017a). Of these, coal and lignite play an important role in power generation in India, as the other energy minerals are in short supply as regards to their occurrence and utilization in the country (Singh et al., 2017b).

Mine trash, also known as overburden material (OB), is heaped on the surface close to open-cast mines, whereas coal is retrieved directly utilizing various underground mining procedures that do not remove overburden material (Liang et al., 2017). This promotes the disintegration of numerous compounds as it travels through coal seams and host rocks, finally transporting vast quantities of suspended particles as well as dissolved materials, which are collected in typical mine drainage

*Ph.D Scholar at AKS University and Area GM, Pench Area, WCL

**Head, Department of Environmental Science, AKS University, Satna

sumps (Singh et al., 2021b). The hydrochemical behaviour of mine seepage water and surrounding water resources must be investigated in order to determine the influence of such mining activities on the water environment. In this regard, many scientists around the world have conducted various studies using various water quality indices, such as the heavy metal pollution index (HPI), heavy metal evaluation index (HEI), and contamination index (CI) (Amiri et al., 2014; Egbueri et al., 2020; Gorgij et al., 2017; Singha et al., 2021). The current study was done to investigate the possibility of PTE contamination in the mine discharge waters of six mines located in the Mahan River catchment area, as well as the potential impact on groundwater and river water sources. To assess pollution levels, five pollution indices were calculated: the heavy metal pollution index (HPI), the heavy metal evaluation index (HEI), the contamination index (CI), the entropy weight-based heavy metal contamination index (EHCI), and the principal component analysis-based metal index. Aside from the classic indices (HPI, HEI, and CI), which are objective-based techniques, two recently developed pollution indices (EHCI and PMI) were selected since their weight computation processes are primarily objective. As a result, the current study focused on 1) the distribution of PTEs in various water sources and their seasonal variation, 2) the use of multiple indexical methods to assess PTE distribution, and 3) the potential impact of mining activity on both groundwater and Mahan River systems. The work's conclusion will highlight the severity of the coal mine's impact on surface water chemistry, the effect on aquifer systems in and around the mining sites, and whether or not any other irregularities exist in the area.

DESCRIPTION OF STUDY REGION

The research region is located in the center of Bishrampur Coalfield, between latitudes 23°00' N and 23°30' N and longitudes 83°00' E and 83°45' E (Figure 1). Metalled roads connect the region to Bishrampur Coalfield's other collieries, including Shivani UG, Jagannathpur OPC, Kalyani UG, Mahamaya UG, Mahan-II OCP, Bhatgaon UG, Nawapara UG, Mahan OC, and Dugga UG. Geographically, the Mahan River and its tributaries regulate the primary drainage component of the coalfield, which flows mostly in the east-west direction of the area before flowing south-north in the north-western part of the research area (Figure 1). The research area has gently undulating trends and elevations ranging from 446 m to

672 m. The area has a tropical monsoon climate, with scorching summers and cold winters, as well as substantial rainfall during the monsoon season. The yearly mean daily temperature ranges from 17.8°C to 30.1°C. May and January have the greatest and lowest average monthly temperatures (42.7° C and 4.4° C, respectively). Between June and September, the study area receives around 87% of the total rainfall. The average yearly rainfall from 1991 to 2017 was approximately 1270 mm. Because of the tropical monsoon environment, the area's relative humidity ranges from moderate to high. During the monsoon season, relative humidity ranges from 55-66% in June to 83-88% in August. Throughout the year, relative humidity varies from 22-39% in April to 83-88% in August. The yearly mean daily humidity is roughly 68% in the morning and 52% in the evening.

MATERIALS AND METHODS

Field sampling and PTEs analysis

To achieve the stated objectives, extensive high-resolution sampling was conducted from all available sources, including groundwater, mine water, and river water samples from various places within and around the Bishrampur coal mining zone (Fig. 1). A total of 96 samples were collected throughout two seasons: pre-monsoon (May 2018) and post-monsoon (November 2017), with 48 from each season. Aside from the research area, two additional samples were taken from separate watersheds with higher altitudes and pollution-free zones/eco zones (i.e., Mainpat) to compare pollution intensity to non-coal mining areas. During fieldwork, polyethylene bottles were used to collect groundwater samples and filtered via 0.45 µm filter paper. Samples were promptly preserved by lowering pH to <2 with HNO₃ and held at 40C until analysis. The concentrations of potentially toxic trace elements (PTEs) such as, Chromium (Cr), Cadmium (Cd), Barium (Ba), Silver (Ag), Copper (Cu), Strontium (Sr), Cobalt (Co), Nickel (Ni), Zinc (Zn), Iron (Fe), Arsenic (As), Lead (Pb), Aluminium (Al), Manganese (Mn), Selenium (Se), and Vanadium (V) in water were analyzed using inductively coupled plasma optical emission spectrometer (ICP-OES) 4300DV Series (Perkin Elmer) by following the standard procedures of APHA (2012). During sample analysis, to ensure the quality control and quality assurance, a standardized water reference material (SRM 1640a; National Institute of Standards and Technology, NIST, United States) was tested. While, in-situ water quality parameters such as pH, total dissolved solids (TDS) and

INDEXICAL METHODS ASSESSING PTES DISTRIBUTION IN MAHAN RIVER COMMAND AREA, CENTRAL INDIA'S COAL MINING ZONE

electric conductivity (EC) for all groundwater samples were measured at each site by means of a hand-held measuring device (SPECTRO, SLE-2603).

Heavy metal pollution in groundwater using multiple indexical methods

The pollution evaluation indices used in this study, namely HPI, HEI, CI, EHCI, and HMI were determined to investigate drinking suitability of groundwater by comparing heavy metal constituents with BIS (2012) standards.

HPI

HPI assesses the overall relevance of each possible poisonous trace element (PTT) for water quality assessment. Individual PTT weights are established by taking into account the relative importance of PTTs to water quality or by computing weight values that are inversely proportionate to the predefined maximum allowed and desirable values for the related PTT (BIS 2012). The weight of the PTTs runs from 0 to 1, with larger values indicating the significance of the specific element in the quality assessment (Prasad et al., 2014). The following formulae were used to estimate the HPI for each groundwater sample:

$$HPI = \frac{\sum_{i=1}^n W_i Q_i}{\sum_{i=1}^n W_i} \quad (1)$$

$$W_i = \frac{1}{S_i} \quad (2)$$

$$Q_i = \sum_{i=1}^n \left\{ \frac{A_i(-)I_i}{(S_i - I_i)} \right\} \times 100 \quad (3)$$

where W_i is the unit weight of i th PTT, the sub-index of i th PTT is represented by Q_i , n is the total number of groundwater samples, A_i , S_i and I_i is the actual, maximum permissible, and maximum desirable concentration of PTT, respectively.

In the present research, the calculated HPI indices of groundwater samples were categorized into five classes

including >100 (unsuitable for drinking), 75-100 (very poor), 50-75 (poor), 25-50 (good), and <25 (excellent).

HEI

HEI method, was introduced by Edet and Offiong (2002), estimates the overall water quality accounting various PTTs in the similar manner like HPI method. In this method of water quality assessment, the actual or measured values of PTTs are divided by the S_i value suggested by BIS (2012) as per the Eq. 4.

$$HEI = \sum_{i=1}^n \frac{A_i}{S_i} \quad (4)$$

Because there is no indicated threshold value for HEI, the level of contamination assessed by this index is based on personal opinion. As suggested by Prasanna et al. (2012), groundwater contamination level was assessed by considering multiple mean approaches to classify the whole groundwater samples into three contamination classes, namely low, moderate, and high.

CI

According to Backman et al. (1997), CI method estimates the degree of contamination by computing the collective effect of different water quality inputs and summarizing them. The computation of CI involves the summing up of individual contamination factors of selected PTTs exceeding the C_{Si} as per Eq. 5 & Eq. 6.

$$CI = \sum_{i=1}^n C_{Fi} \quad (5)$$

$$C_{Fi} = \frac{C_{Ai}}{C_{Si}} - 1 \quad (6)$$

where the contamination factor i th PTT is represented by C_{Fi} , C_{Ai} and C_{Si} is measured concentration and the maximum permissible limit of i th PTT.

In the present research work, CI values of groundwater were classified into three contamination levels such as low (CI:<1), moderate (CI:1-3), and high (CI:>3) (Edet and Offiong 2002; Backman et al. 1997).

EHCI

The water quality assessment using EHCI mainly works on the information congregated by the entropy system (Singh et al. 2021). The entropy weight (w_j) of PTTs is calculated based on Shannon entropy information technique and then coupled with the sub-indices (Q_i) of respective PTT provides the EHCI values as per the following Eqs.

$$EHCI = \sum_{j=1}^n w_j Q_i \quad (8)$$

$$Q_i = \left(\frac{A_i}{S_i} \right) \times 100 \quad (9)$$

$$w_j = (1 - E_j) / \sum_{j=1}^m (1 - E_j) \quad (10)$$

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^m \{P_{ij} \cdot \ln P_{ij}\} \quad (11)$$

$$P_{ij} = \frac{y_{ij}}{\sum_{i=1}^m y_{ij}} \quad (12)$$

$$y_{ij} = \frac{x_{ij} - \min_{i=1,2,3,\dots,m} (x_{ij})}{\max_{i=1,2,3,\dots,m} (x_{ij}) - \min_{i=1,2,3,\dots,m} (x_{ij})} \quad (13)$$

where j th PTT entropy weight is represented by w_j , E_j is the entropy of j th PTT, in i th groundwater sample, the probability of occurrence of j th PTT is represented by P_{ij} , the normalized value in i th groundwater sample ($i=1, 2, 3, \dots, m$ and $j=1, 2, 3, \dots, n$) for j th PTT is represented by y_{ij} , and for i th groundwater sample the measured concentration of j th PTT is represented by x_{ij} .

The study categorized computed EHCI values into four categories: unsuitable (>200), poor (150-200), average (100-150), good (50-100), and excellent (<50) (Amiri et al., 2014).

HMI

As recommended by Dash et al. (2019), the Principal Component Analysis (PCA)-based HMI also assesses water quality. The factors bearing with an eigenvalue more than 1 are extracted in the form of factor loading during the PCA method. In this process, the relative eigenvalues and factor loadings are then multiplied to get heavy metal weights. Later, the calculated weights are further used to estimate the HMI values of water samples as per the equation below.

$$HMI = \sum_{i=1}^n \left(p_i \times \frac{A_i}{S_i} \right) \times 100 \quad (14)$$

where i th heavy metal's PCA-based weight is represented by p_i . In this research work, the estimated HMI values are classified into five sub-categories such as, unsuitable (>300), poor (200-300), average (100-200), good (50-100), and excellent (<50).

RESULTS AND DISCUSSION

Groundwater compliance w.r.t drinking water standards and statistical analysis of PTEs dynamics

The descriptive statistics of the PTEs concentrations for all locations within the study area illustrates that the average concentration of Mn, Pb, Ni and Fe (Pre-monsoon) and Mn, Pb, Ni, Fe and Al (Post-monsoon) in different water sources of the study area were higher than the permissible limits, as suggested by Bureau of Indian Standards (BIS, 2012). The mean concentration of all parameters except Al, Fe and Mn were higher during pre-monsoon than that of post-monsoon (Table 1). This testifies the seasonal variation in the PTEs concentration; however, the high concentration of Al, Fe and Mn reported during post-monsoon is attributed to interaction of mine seepage water alongside precipitation water over the mine catchments (Fig. 1) with the overburden dumps and working faces and as consequent release of these constituents into mine discharge water. Whereas, evaporation, intensive agricultural activity (Sugarcane) and coal mining allied industries are the controlling factors for elevated PTE concentrations reported during pre-monsoon season. The results of water samples compliance with respect to suitability of drinking water

INDEXICAL METHODS ASSESSING PTEs DISTRIBUTION IN MAHAN RIVER COMMAND AREA, CENTRAL INDIA'S COAL MINING ZONE

(BIS, 2012) reveal that 48% of water samples during pre-monsoon season fell below the acceptable limit of pH (6.5) and it is 44% in the case of the post-monsoon season. Similarly, the PTEs namely, Mn (18%), Cu (4%), Pb (8%), Ni (18%), Cd (2%), Al (4%), Cr (2%), and Fe (30%) during pre-monsoon and while Mn (15%), Pb (6%), Ni (15%), Cd (2%), Al (15%), Fe (46%) and Ba (4%) samples in post-monsoon season exceeded permissible limits (BIS, 2012). The remaining elements, such as Zn, As, Se, and Ag, are completely within acceptable limits during both seasons (Table 1).

Discern seasonality of PTEs and compare water resources using the Caboi plot.

Groundwater PTEs concentration largely governed by the chemical composition of host rock with which it interacts alongside climatic and anthropogenic factors. In general, the pH of the groundwater is one of the factors that drive the mobility of cationic species of the water. Therefore, the relationship between pH and PTEs content of the groundwater has been traced in the present study by using Caboi diagram (Caboi et al., 1999). The plot classified (Figure. 2) most of the groundwater, river water and mine water samples of both the seasons as near neutral low-metal type and this particular cluster of the samples are free from acid mine drainage and contamination. Whereas, a few samples mostly the mine water samples of Bhatgaon UG, Mahamaya UG, and Mahan OC (PR40, PR41, PR42, PR43, PR47, and PR48) along with a river water samples (PR44) located proximate to these mines were observed as Acid –High-metal. The low pH range could be attributed to the oxidation of pyrite-bearing minerals present in coal cleat faces when exposed to an aeration zone and water, which also accounts for the high concentration of PTEs in the research area. This clearly shows that, in addition to mineral dissolution, AMD affects the mine water samples in this cluster. Most notably, post-monsoon samples have a higher concentration of PTEs than pre-monsoon ones.

Evaluation of PTTs pollution and spatial distribution of pollution indices

All the pollution evaluation indices have been estimated for both seasons, individually for all the sampling stations (Table 2). Statistically, the 14% (HPI), 14% (HEI), 18% (CI), 14% (EHCI), and 20% (HMI) of the samples were above the standards during the pre-monsoon season. A

total of 10% (HPI), 10% (HEI), 15% (CI), 15% (EHCI), and 17% (HMI) of samples exceeded standards during the post-monsoon season. However, the indices for all the groundwater and river water samples bearing a few locations in proximity to the mining area, are below the critical limit. Consequently, the majority of the dug wells and bore wells in the study area are not polluted and are safe for human consumption.

To examine the spatial distribution of pollution load and seasonal change in the research area's numerous water sources, a thematic map containing all five indices was created (Figure 3). Metal contamination was higher in the north-western half of the research region at all times of the year, according to all ten spatial distribution maps of HPI, HEI, CI, EHCI, and HMI, due to geogenic influxes and mining activities that hastened the dissolving of toxic metals on contact. Among all the indexical methods, the thematic map of the EHCI for different seasons was chosen for evaluation (Figure 3). It is apparent from the EHCI thematic map that the highest pollution anomalies (>200) were reported in the north-western part of the study area, where Mahan OCP, Bhatgaon UG, and Mahamaya UG mines are in operation. Thus the water samples from this region are classified as a very poor and unsuitable category and the rest of the locations fall in low metal pollution (< 50). Contrastingly, the results of the indexical methods indicate that the mine water samples from the pre-monsoon season (i.e., 1102) possess a comparatively less pollution load than the post-monsoon season (i.e., 2193) (Table 2). This can be attributed to a variety of anthropogenic factors; the movement of heavy earthmoving equipment (HEMM) at the mine site and the interaction of seepage water through the mine workings. Other than this runoff of rainfall with the OB dumps may be a plausible reason, as the study area received abundant precipitation (1500 mm). Therefore, it is prudent to conclude that the mining activity in the Mahan River catchment area does not pose any appreciable threat to the groundwater and surface water system. Its impact is confined to the mine periphery locations.

CONCLUSIONS

This study examines the distribution of PTEs in different water sources and their seasonal variations, the application of multiple indexical methods to assess PTE distributions, and the interpretation of the impacts (if any) of mining activities on groundwater and the Mahan River

system. The result of water samples compliance concerns drinking water standards (BIS, 2012) at most locations bearing Mn, Pb, Ni, and Fe constituents. Seasonal changes in the different indexical approaches revealed that 20% of samples (HMI) in the pre-monsoon season and 17% of samples in the post-monsoon season are unsuitable for immediate consumption. The remaining indices (HPI, HEI, CI, and EHCI) revealed that 85 to 90% of the total samples are suitable for consumption and hence classed as good water. The Caboi plot indicates that most of the groundwater, river water and mine water samples from both seasons are in “near neutral low-metal type” and this particular cluster of the samples are free from acid mine drainage and contamination. Meanwhile, some samples, mainly mine water samples from Mahan OC, Mahamaya UG, and Bhatgaon UG (PR40, PR41, PR42, PR43, PR47 and PR48) as well as river water samples (PR44) located proximate to these mines were observed as “Acid - High Metal”. This clearly shows that the mine water samples from this cluster are damaged by AMD in addition to mineral dissolution. Therefore, it is prudent to infer that mining activities in the Mahan River catchment area offer no serious hazard to groundwater and surface water, and their impact is limited to the mine’s perimeter.

ACKNOWLEDGEMENTS

The authors are grateful to the management of CMPDIL, Ranchi, SECL, Bilaspur, and AKS University, Satna for providing facilities for the publishing of this study. We are also grateful to the CSIR-Central Institute of Mining and Fuel Research, Dhanbad, for some analytical assistance. The opinions expressed in this work are solely those of the authors and do not necessarily reflect the views of the organization to which they belong.

STATEMENTS AND DECLARATIONS

Funding:

No funding was provided to help in the preparation of this manuscript. The authors disclose no competing interests relevant to the content of this article.

Declarations of conflict of interest

It is assured that the work described has not been published elsewhere and there is no conflict of interest.

AUTHORS' CONTRIBUTIONS

Nirmal Kumar: Have made a substantial contribution to the acquisition of field data, analysis, and interpretation of data for the article.

Mahendra Kumar Tiwari: Have made a substantial contribution to the interpretation of data for the article.

Rambabu Singh: Have made a substantial contribution to the design of the article, interpretation of data and drafted the article and brought it to current form.

Sudhakar Singha: Preparation of various maps/ figures using different software.

Soumya S. Singha: Computation of different indices and their implications.

Abhay Kumar Singh: Lab work and entire analysis were performed.

Prasad Babu K: Associated in interpretation of water quality indices and preparation of various maps/ figures.

DATA AVAILABILITY

The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

REFERENCES

Amiri, V., Rezaei, M., Sohrabi, N., 2014. Groundwater quality assessment using entropy weighted water quality index (EWQI) in Lenjanat, Iran. *Environmental Earth Sciences* 72 (9), 3479e3490. <https://doi.org/10.1007/s12665-014-3255-0>.

APHA (American Public Health Association) (2012) *Standard Methods for the Examination of Water and Waste Water*, APHA, Washington, DC.

BIS (Bureau of Indian Standards) (2012) IS: 10500, Indian Standard for Drinking Water Specification. 2nd Revision, New Delhi.

Backman B, Bodis D, Lahermo P, Rapant S, Tarvainen T (1997) Application of a groundwater contamination index

INDEXICAL METHODS ASSESSING PTES DISTRIBUTION IN MAHAN RIVER COMMAND AREA, CENTRAL INDIA'S COAL MINING ZONE

in Finland and Slovakia. *Environ Geol* 36:55–64. doi:10.1007/s002540050320.

Caboi R, Cidu R, Fanfani L, Lattanzi P, Zuddas P (1999) Environmental mineralogy and geochemistry of the abandoned Pb–Zn Montevecchio–Ingurtosu mining district, Sardinia, Italy. *Chron Rech Min* 534:21–28.

Dash, S., Borah, S.S., Kalamdhad, A., 2019. A modified indexing approach for assessment of heavy metal contamination in Deepor Beel, India. *Ecol. Indic.* 106, 105444.

Dhakate, R., Ratnal, G.V. & Laxmankumar, D 2020. Evaluation of heavy metals contamination in soils at Peenya Industrial Area, Bengaluru, India. *Arab J Geosci* 13, 880. <https://doi.org/10.1007/s12517-020-05900-y>.

Edet AE, Offiong OE (2002). Evaluation of water quality pollution indices for heavy metal contamination monitoring. A study case from Akpabuyo–Odukpani area, Lower Cross River Basin (south eastern Nigeria). *Geoj* 57:295–304. doi:10.1023/B:GEJO.0000007250.92458.de.

Edokpayi, J.N., Odiyo, J.O. and Durowoju, O.S. (2017). Impact of Wastewater on Surface Water Quality in Developing Countries: A Case Study of South Africa. In: Tutu, H., Ed., *Water Quality, InTechOpen*, London, Chap. 18, 401–416. <https://doi.org/10.5772/66561>.

Egbueri, J.C., Ezugwu, C.K., Ameh, P.D. *et al.*, (2020). Appraising drinking water quality in Ikem rural area (Nigeria) based on chemometrics and multiple indexical methods. *Environ Monit Assess* 192, 308 (). <https://doi.org/10.1007/s10661-020-08277-3>.

Emenike, P.C., Tenebe, I., Ogarekpe, N. *et al.*, (2019). Probabilistic risk assessment and spatial distribution of potentially toxic elements in groundwater sources in Southwestern Nigeria. *Sci Rep* 9, 15920. <https://doi.org/10.1038/s41598-019-52325-z>.

Gleeson, T., Befus, K.M., Jasechko, S., Luijendijk, E., Cardenas, M.B., 2016. The global volume and distribution of modern groundwater. *Nat Geosci.* <https://doi.org/10.1038/NCEO2590>.

Gorgij, A.D., Kisi, O., Moghaddam, A.A., Taghipour, A., 2017. Groundwater quality ranking for drinking purposes, using the entropy method and the spatial autocorrelation index. *Environmental earth sciences* 76 (7), 269.

Kumar, N., Tiwari, M.K., Singh, R. *et al.*, 2022. Chemometrics in Ascertaining Hydrogeochemical Characteristics of Coal Mine Discharge vis-à-vis Behaviour of Surface and Groundwater Resources of the Mahan River Catchment Area, Central India. *Mine Water Environ* 41, 518–532. <https://doi.org/10.1007/s10230-022-00854-x>.

Liang, Z., Ren, T., Ningbo, W., 2017. Groundwater impact of open cut coal mine and an assessment methodology: A case study in NSW. *International Journal of Mining Science and Technology* 27:861–866.

Panigrahy BP, Singh PK, Tiwari AK, Kumar B, Kumar A (2015). Assessment of heavy metal pollution index for groundwater around Jharia coalfield region, India. *J Bio Environ Sci* 6(3):33–39.

Prasad B, Kumari P, Bano S, Kumari S (2014). Ground water quality evaluation near mining area and development of heavy metal pollution index. *Appl Water Sci.* doi:10.1007/s13201-013-0126-x.

Prasanna MV, Praveena SM, Chidambaram S, Nagarajan R, Elayaraja A (2012) Evaluation of water quality pollution indices for heavy metal contamination monitoring: a case study from Curtin Lake, Miri City, East Malaysia. *Environ Earth Sci* 67:1987–2001.

Singha SS, Pasupuleti S, Singha S, Singh R, Kumar S (2021). Prediction of groundwater quality using efficient machine learning technique. *Chemosphere.* <https://doi.org/10.1016/j.chemosphere.2021.130265>.

Singh, R., Gayen, A., Kumar, S., Dewangan, R., 2021. Geo-spatial distribution of arsenic contamination of groundwater resources in intricate crystalline aquifer system of Central India: Arsenic toxicity manifestation and health risk assessment, *Human and Ecological Risk Assessment: An International Journal*, 27:6, 1588–1612. DOI: 10.1080/10807039.2020.1865787.

Singh, R., Venkatesh, A.S., Syed, T.H., Surinaidu, L., Pasupuleti, S., Rai, S.P., Kumar, M., 2018. Stable isotope

systematic and geochemical signatures constraining groundwater hydraulics in the mining environment of the Korba Coalfield, Central India. *Environ Earth Sci.* 77:548. <https://doi.org/10.1007/s12665-018-7725-7>.

Singh R, Syed TH, Kumar S, Kumar M, Venkatesh AS (2017a) Hydrogeochemical assessment of surface and groundwater resources of Korba coalfield, Central India: environmental implications. *Arab J Geosci* 10:318. doi: 10.1007/s12517-017-3098-6.

Singh R, Venkatesh AS, Syed TH, Reddy AGS, Kumar M, Kurakalva RM (2017b) Assessment of potentially toxic trace elements contamination in groundwater resources of the coal mining area of the Korba Coalfield, Central India. *Environ Earth Sci* doi:10.1007/s12665-017-6899-8.

Singh R, Venkatesh AS, Syed TH, Surinaidu L, Pasupuleti S, Rai SP, Kumar M (2018) Stable isotope systematic and geochemical signatures constraining groundwater

hydraulics in the mining environment of the Korba Coalfield, Central India. *Environ Earth Sci* 77:548. doi.org/10.1007/s12665-018-7725-7.

Singh R, Gayen A, Kumar S, Dewangan R (2021a). Geospatial distribution of arsenic contamination of groundwater resources in intricate crystalline aquifer system of Central India: arsenic toxicity manifestation and health risk assessment. *Hum Ecol Risk Assess.* doi: 10.1080/10807039.2020.1865787.

Singh R, Narayan ID, Doley T, Kumar N, Bandyopadhyay D, Kisku DK (2021b). Climate-resilient groundwater rationing in the mining environment: an operational framework from India. *Environ Earth Sci.* doi: 10.1007/s12665-021-09732-1.

Wang, Y., and Li, P., 2022. Appraisal of shallow groundwater quality with human health risk assessment in different seasons in rural areas of the Guanzhong Plain (China). *Environmental Research.* <https://doi.org/10.1016/j.envres.2021.112210>.

Table 1: Statistical analysis of PTEs dynamics and comparison with drinking suitability (BIS 2012).

Chemical constituent	Pre-monsoon (n=50)					Post-monsoon (n=48)					Drinking water standards (BIS 2012)	
	Minimum	Maximum	Mean	SD	% of the sample above PL	Minimum	Maximum	Mean	SD	% of the sample above PL	Requirement (acceptable limit)	Permissible limit (PL) in the absence of alternate source
pH	3.33	7.87	6.45	1.19	48.00%	3.57	8.06	6.56	1.21	43.75%	6.50	8.50
EC	57.00	3859.00	420.06	674.35		89.30	2391.00	373.84	459.86			
Mn	0.02	5214.94	654.53	1468.57	18.00%	0.42	17898.75	1185.16	3393.25	14.6%	100.00	300.00
Cu	0.03	163.41	5.86	24.53	4.00%	0.16	121.03	5.06	18.36	0.0%	50.00	1500.00
Pb	0.85	124.65	28.01	41.64	8.00%	0.29	74.25	19.68	27.68	6%	10.00	No relaxation
Zn	0.98	3596.20	159.31	549.79	0.00%	0.01	2516.95	158.89	459.53	0.0%	5000.00	15000.00
Ni	1.48	1604.62	73.12	258.38	18.00%	1.92	939.02	57.48	178.43	14.6%	20.00	No relaxation
Co	0.06	989.28	40.11	155.08		0.19	588.63	32.08	107.63			
As	0.03	3.67	0.46	0.65	0.00%	0.06	4.24	0.44	0.63	0.0%	10.00	50.00
Se	0.15	7.52	0.60	1.07	0.00%	0.04	7.00	0.60	1.07	0.0%	10.00	No relaxation
Cd	0.05	6.06	1.05	1.76	2.00%	0.00	5.57	0.73	1.47	2.1%	3.00	No relaxation
Al	2.98	784.70	58.74	150.84	4.00%	9.19	28930.41	1737.22	5586.56	14.6%	30.00	200.00
Cr	0.54	52.72	2.04	7.30	2.00%	0.84	21.71	2.27	3.89	0.0%	50.00	No relaxation
V	0.00	3.32	0.88	0.83		0.10	7.68	1.08	1.25			
Ag	0.00	0.66	0.05	0.14	0.00%	0.00	1.64	0.19	0.44	0.0%	100.00	No relaxation
Fe	15.91	6043.36	471.15	994.17	30.00%	34.18	7696.49	661.93	1298.62	45.8%	300.00	No relaxation
Sr						7.55	2740.34	232.63	449.32			
Ba						13.03	846.80	165.41	174.85	4.2%	700	No relaxation

INDEXICAL METHODS ASSESSING PTES DISTRIBUTION IN MAHAN RIVER COMMAND AREA, CENTRAL INDIA'S COAL MINING ZONE

Table 2: Summary of multiple PTEs indices of water samples

Catchment	Location	Sample Code	Source Type	Lat. (N)	Long. (E)	Pre-monsoon (n=50)					Post-monsoon (n=48)				
						HPI	HEI	CI	EHCI	HMI	HPI	HEI	CI	EHCI	HMI
ahan II OCP	Gonda	PR1	GW	23.426308	83.058688	3.64	1.33	0.07	13.45	39.38	3.55	2.32	0.12	21.04	46.17
	Mahan River S 7	PR2	RW	23.450831	83.076286	2.76	1.26	0.02	12.78	37.16	2.93	1.14	0.00	10.95	30.30
	Parvatipur	PR3	GW	23.439232	83.109604	2.29	0.78	0.00	7.92	22.92	2.95	0.94	0.00	9.33	25.73
	Mahan River S 6	PR4	RW	23.437246	83.079125	3.20	1.58	0.29	15.99	46.75	3.46	1.27	0.00	12.18	32.87
	Banki River	PR5	RW	23.417644	83.099684	2.04	0.71	0.00	7.24	20.60	2.70	1.07	0.00	10.33	26.74
	Palda	PR6	GW	23.408830	83.098433	2.19	0.71	0.00	6.84	19.61	3.46	1.92	0.00	17.50	48.23
	Chhatarpur Para	PR7	GW	23.411054	83.076042	2.71	0.63	0.00	6.17	18.17	3.96	1.09	0.00	10.66	31.59
	Bagrd	PR8	GW	23.370978	83.107332	4.53	1.68	0.00	16.00	47.00	3.69	1.47	0.04	14.23	42.26
	Dharampur	PR9	GW	23.405496	83.177715	3.84	0.85	0.00	7.98	24.76	4.82	0.90	0.00	8.13	25.65
	Maridand	PR10	GW	23.346832	83.159758	3.72	1.97	0.66	19.97	59.70	4.09	2.04	0.72	20.40	60.06
	Mahan River S 2	PR11	RW	23.333987	83.150358	2.57	1.03	0.00	10.45	29.96	2.65	1.06	0.00	10.31	28.49
	Gohangar Nala	PR12	RW	23.343563	83.170862	2.57	0.98	0.00	9.88	28.24	3.33	1.45	0.16	14.40	41.78
	Kotripara	PR13	GW	23.350055	83.229097	3.05	1.10	0.00	10.69	31.25	5.89	1.54	0.00	14.56	42.41
	Mahan II Inlet	PR14	MW	23.361098	83.224560	4.21	1.99	0.56	20.18	58.88	8.61	5.09	2.41	49.23	144.01
	Mahan II Outlet	PR15	MW	23.363498	83.227038	4.25	2.06	0.64	20.88	61.21	6.24	2.94	1.44	29.39	87.82
	Choura	PR16	GW	23.372049	83.227933	10.54	0.78	0.00	6.85	21.36	4.19	0.95	0.00	8.58	25.51
	Silphili	PR17	GW	23.418983	83.254764	2.58	0.71	0.00	6.63	18.50	6.06	1.66	0.00	14.83	44.91
	Mahan River S 1	PR18	RW	23.325253	83.191539	2.45	0.81	0.00	8.10	22.87	2.74	0.99	0.00	9.70	26.97
	Khargawan	PR19	GW	23.306809	83.192387	2.89	0.68	0.00	6.66	18.50	8.52	2.00	0.25	20.60	51.29
	Kalyanpur	PR20	GW	23.243182	83.191314	4.43	0.83	0.00	7.87	24.69	4.54	0.98	0.00	9.24	29.06
Karwan	PR21	GW	23.241610	83.052178	33.47	5.16	2.75	44.31	153.33	4.74	0.97	0.00	8.69	25.70	
Hiradabri/Maheshpur	PR22	GW	23.216557	83.070416	5.93	1.13	-2.73	10.27	33.14	3.50	0.96	0.00	9.23	27.45	
awapara UG	Nawapara Inlet	PR23	MW	23.221277	83.089743	3.10	1.02	0.00	10.11	30.34	3.67	1.54	0.22	15.20	45.58
	Nawapara Outlet	PR24	MW	23.221277	83.089743	2.95	1.04	0.00	10.41	30.98	3.17	1.51	0.26	14.82	45.50
Latori	PR25	GW	23.230705	83.095154	5.28	0.77	0.00	6.89	23.87	4.98	0.98	0.00	8.74	27.38	
Tulsi	PR26	GW	23.267560	83.099716	3.85	0.78	0.00	7.49	23.56	5.59	2.03	0.56	20.20	59.94	
Chikni	PR27	GW	23.307508	83.050675	3.07	1.02	0.00	10.12	29.09	3.54	1.22	0.00	11.93	35.71	
Bojha	PR28	GW	23.319685	83.123626	4.58	0.84	0.00	7.69	22.90	3.74	1.24	0.00	12.16	36.40	
Mahan River S 3	PR29	RW	23.339905	83.139923	2.35	0.69	0.00	6.87	19.52	2.81	1.02	0.00	9.98	27.97	
Banki Nala	PR30	RW	23.331107	83.138494	2.33	0.73	0.00	7.39	21.03	2.95	1.25	0.00	12.30	35.35	
Mayapuri	PR31	GW	23.345631	83.112032	3.05	1.02	0.00	10.26	29.70	3.10	1.27	0.02	12.61	37.14	
Galphuli Nala	PR32	RW	23.312628	83.113111	2.70	0.88	0.00	8.89	25.31	2.42	1.16	0.00	10.86	25.14	
Jhigador	PR33	GW	23.321008	83.087181	3.54	0.48	0.00	4.31	14.37	4.64	0.77	0.00	6.96	21.52	
ii UG	Shivani Inlet	PR34	MW	23.349753	83.074522	3.28	1.06	0.00	10.50	31.19	3.50	1.79	0.41	17.56	50.62
	Shivani Outlet	PR35	MW	23.348922	83.074411	3.09	1.10	0.00	11.00	32.82	3.45	1.72	0.39	16.93	50.01
Kodasa	PR36	GW	23.356298	83.063490	3.40	1.16	0.00	11.53	34.68	10.25	2.19	0.46	20.68	63.00	
Jarhi	PR37	GW	23.356878	83.038126	2.67	0.48	0.00	4.62	13.91	3.43	0.64	0.00	5.93	18.36	
Dugga	PR38	GW	23.351837	83.012246	2.23	0.50	0.00	4.73	13.35	3.18	0.48	0.00	4.35	11.28	
aon UG	Bhatgaon	PR39	GW	23.350525	83.001077	32.68	9.15	6.00	81.37	244.61	3.58	1.09	-2.04	10.60	32.23
	Bhatgaon Inlet	PR40	MW	23.357330	83.006540	72.88	23.35	19.36	206.91	581.14	61.83	22.03	17.85	185.00	481.05
Bhatgaon Outlet	PR41	MW	23.357330	83.006540	106.38	31.14	26.87	274.56	786.04	131.21	47.77	42.96	395.25	914.80	
Mahan 1 Inlet	PR43	MW	23.383972	83.014142	623.63	92.44	86.32	785.15	2629.90	765.93	269.51	118.39	2193.01	3501.76	
n 1 OCP	Mahan 1 Outlet	PR42	MW	23.383972	83.014142	829.21	127.68	118.51	1102.69	3838.90	632.70	218.81	212.45	1776.66	3306.04
	Mashan Nala	PR44	RW	23.383263	83.049987	63.95	23.72	19.48	211.54	568.85	91.65	29.45	25.82	237.89	548.44
Mahan River S 5	PR45	RW	23.417465	83.065573	3.23	1.35	0.00	13.17	34.19	2.96	1.19	0.00	11.17	30.87	
Pondi	PR46	GW	23.390450	83.184167	10.16	6.27	3.56	63.15	171.31	9.24	2.82	0.70	27.12	82.06	
maya UG	Mahamaya Inlet	PR47	MW	23.366758	83.004386	97.40	23.04	17.99	203.28	603.70	176.48	109.38	103.82	878.91	973.04
	Mahamaya Outlet	PR48	MW	23.366758	83.004386	99.31	24.89	19.85	221.90	660.18	191.87	117.99	112.29	950.97	1069.51
point	PR49	RW	22.828169	83.363311	2.09	1.57	0.00	14.59	17.71						
ani	PR50	GW	22.878028	83.281211	2.17	1.04	0.00	10.12	19.66						
Statistical summary of multiple pollution indices (-River Water, MW- Mine Water, GW- Groundwater, DW- Dug Well, HP- Hand Pump, and TW- Tube Well)					Mean	42.09	8.16	6.40	71.97	227.82	46.43	18.24	13.33	150.03	259.91
					Min	2.04	0.48	-2.73	4.31	13.35	2.42	0.48	-2.04	4.35	11.28
					Max	829.21	127.68	118.51	1102.69	3838.90	765.93	269.51	212.45	2193.01	3501.76
					Percentage of samples exceeded standards	14.0%	14.0%	18.0%	14.0%	20.0%	10.4%	10.4%	14.6%	14.6%	16.7%

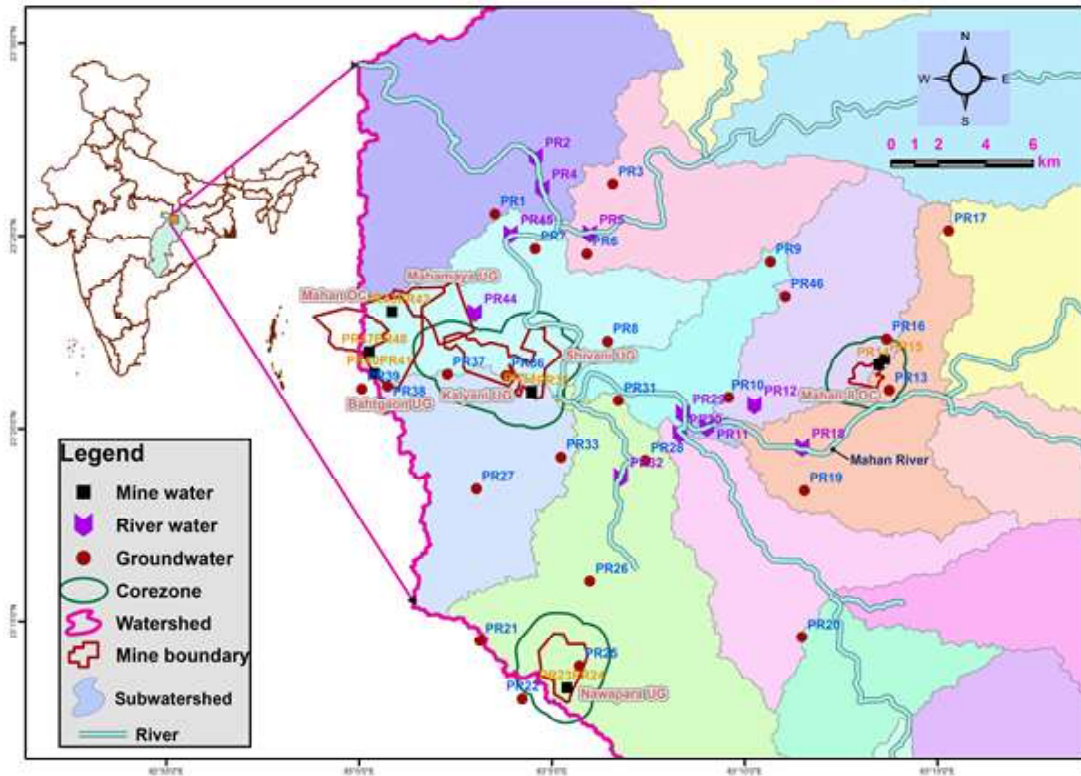


Figure 1: Map of the study area with mines, sampling locations and sub-watersheds

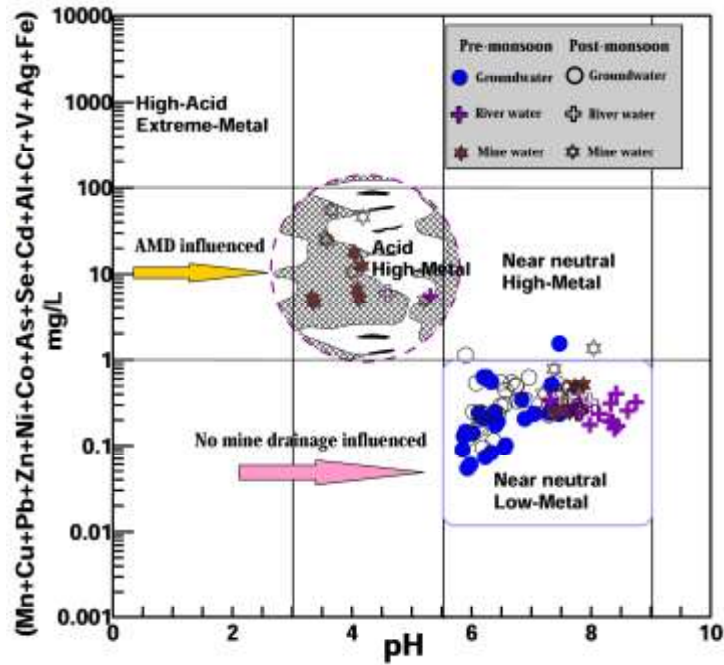


Figure 2: The Caboï diagram shows the classification of surface and groundwater as a function of the total heavy metal load relative to the pH of the study area.

INDEXICAL METHODS ASSESSING PTES DISTRIBUTION IN MAHAN RIVER COMMAND AREA, CENTRAL INDIA'S COAL MINING ZONE

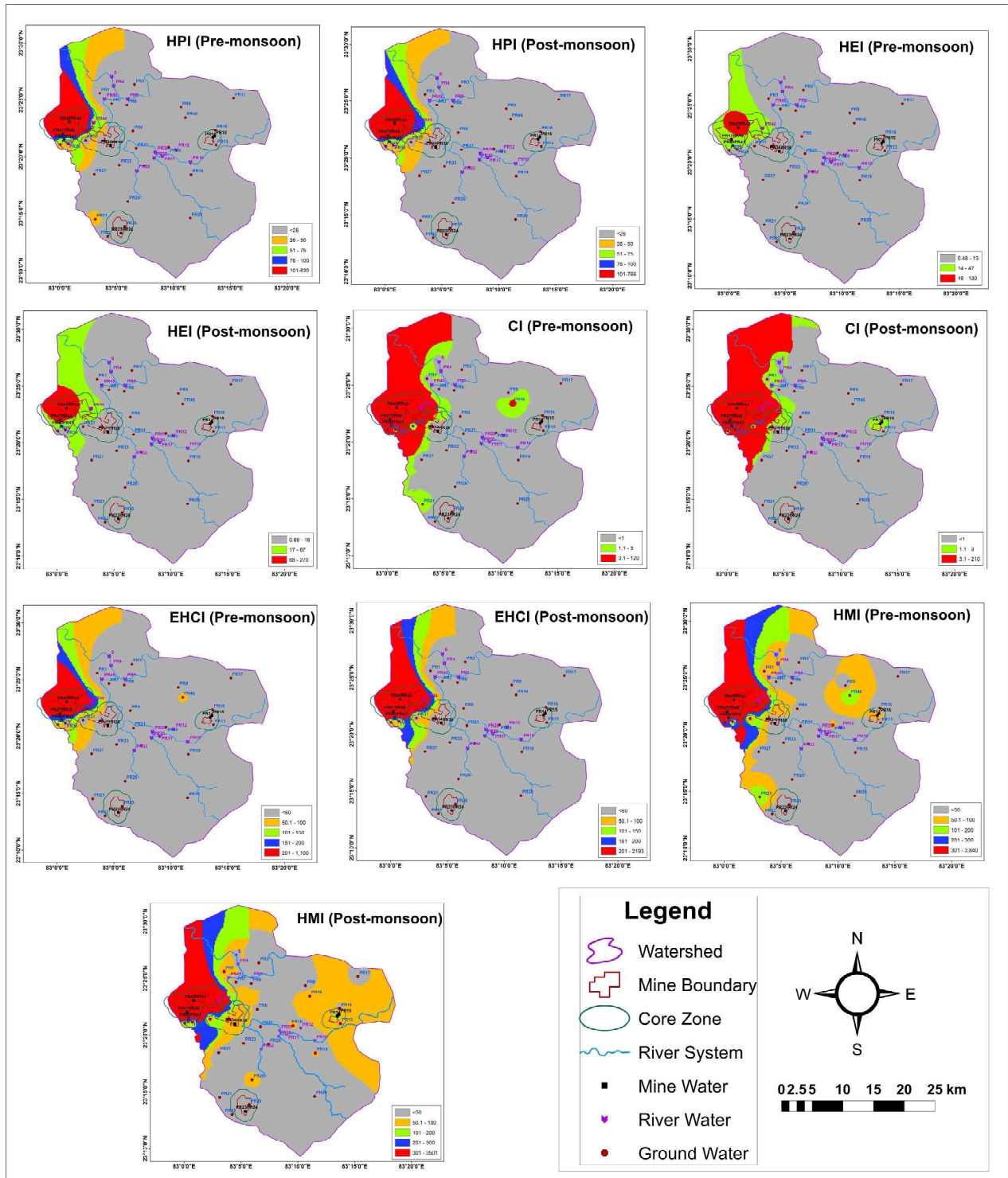


Figure 3: Thematic map showing the spatiotemporal distribution of the multiple indices

Backfilling in Opencast Mines Using Red Mud - An Indian Case Study

Aditya Jha*

ABSTRACT

Land in India, has been very scarce and any land meant for mining needs to be rehabilitated to bring back to its original use. Keeping this in virw several policy changes have been made in the regulations. One important legislative measure has been MCDR 1988, vide Rules 33 & 34 provide that: Rule 33(4): Wherever possible, the waste rock, overburden, etc. shall be backfilled into the mine excavations with a view to restoring the land to its original use as far as possible.

The mining industry generates significant quantities of waste materials, resulting in environmental and operational challenges. One such waste material, red mud, is a byproduct of the alumina extraction process and is commonly disposed of in large storage facilities, posing a potential risk to the environment. To address these challenges and explore sustainable alternatives, this study investigates the feasibility of using red mud as a backfill material for mining voids. The objective of this paper is to assess the engineering properties and environmental impacts of utilizing Red Mud as a backfill material. The study includes laboratory experiments to determine the geotechnical characteristics of red mud, such as strength, permeability, and compaction properties. Additionally, various physical and chemical tests are conducted to evaluate the environmental suitability of red mud as a backfill material, considering leaching potential and long-term stability. The results indicate that red mud possesses desirable geotechnical properties, including adequate strength and compaction characteristics, making it a potential candidate for backfilling in mining voids. Furthermore, the chemical analyses demonstrate a low potential for leaching harmful substances, which mitigates concerns related to groundwater contamination and environmental risks.

The utilization of red mud as a backfill material offers several advantages, including waste management benefits, cost-effectiveness, and sustainability. By repurposing this industrial waste, mining companies can reduce the need for traditional backfill materials and alleviate the demand for natural resources, contributing to a more circular economy and reducing the industry's environmental footprint.

INTRODUCTION

RED MUD

Red mud, also known as bauxite residue, is a byproduct of the Bayer process, which is used to extract aluminum from bauxite ore. Bauxite is the primary source of aluminum, and the Bayer process involves refining bauxite to extract alumina (aluminum oxide). During this process, the insoluble components of bauxite, including iron oxides, silica, and other impurities, become concentrated in the red mud.

Red mud gets its name from its characteristic red color, which is due to the presence of iron oxides. The composition of red mud can vary depending on the source of bauxite and the specific refining process used. It typically consists of fine particles with a high pH level, making it highly alkaline.

The management of red mud has been a significant environmental concern due to its caustic nature and potential for environmental impacts if not properly managed. Improper disposal of red mud has been associated with environmental pollution, particularly if it contaminates water bodies or soil. In some cases, red mud spills or leaks from storage facilities have caused

*M.Tech(Mining) Student, AKS University, Satna (M.P) & Faculty Member of Mining, GEC Jagdalpur, CG

extensive damage to ecosystems and human communities.

Efforts have been made to find sustainable solutions for red mud management, including recycling and reusing it in various applications such as construction materials, soil amendments, and in the production of iron or cement. Additionally, research continues to find innovative ways to reduce its environmental impact and find economically viable uses for this byproduct.

HOW RED MUD IS PRODUCED ?

Red mud is a byproduct of the Bayer process, the principal means of refining bauxite to produce Alumina. The resulting alumina is the raw material for producing aluminum by the Hall-Heroult process. A typical bauxite plant produces one to two times as much as red mud as alumina. The ratio is dependent on the type of bauxite used in the refining process and the extraction conditions. Mining of bauxite in India is purely by open-pit methods and they occur mostly in hill tops at very high altitudes. Alumina is extracted using sodium hydroxide under conditions of high temperature and pressure. The insoluble part of the bauxite (the residue) is removed, giving rise to a solution of sodium aluminate, which is then seeded with an aluminium hydroxide crystal and allowed to cool which causes the remaining aluminium hydroxide to precipitate from the solution. Some of the aluminium hydroxide is used to seed the new batch, while the remainder is calcined (heated) at over 1000°C in rotary kilns or fluid flash calciners to produce aluminium oxide (alumina). The alumina content of the bauxite used is normally between 42% and 50% but ores with a wide range of alumina content can be used. The aluminium compound may be present as Gibbsite ($\text{Al}(\text{OH})_3$), Boehmite ($\gamma\text{-AlO}(\text{OH})$) or Diaspore ($\alpha\text{-AlO}(\text{OH})$). The residue invariably has a high concentration of iron oxide which gives the product a characteristic red color.

SOURCES OF RED MUD

The major sources of red mud include:

Bauxite mines: Bauxite ore is mined from open-pit mines or underground mines in various countries with significant bauxite deposits. The main bauxite-producing regions

include Australia, China, Brazil, India, Guinea, and Indonesia.

Alumina refineries: Bauxite when treated by Bayer process the impurities in bauxite, such as iron oxides, silica, and titanium dioxide, become concentrated in the form of red mud during the refining process.

It's important to note that the composition of red mud can vary depending on the specific bauxite source, refining process, and other factors. Additionally, the generation of red mud is a concern due to its caustic nature and potential environmental impact if not managed properly. Efforts have been made to find sustainable solutions for red mud management, including recycling and reusing it in various applications to reduce its environmental impact.

BAUXITE & ITS TYPES

The elemental form of aluminium is not found in nature since it is a reactive metal. A vast variety of minerals, typically in combination with other oxides, most notably silica and iron oxides, contain aluminium almost completely as the oxide.

Gibbsite ($\text{Al}(\text{OH})_3$), also known as Alumina trihydrate or hydrate ($\text{Al}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$) in the business, Boehmite ($\text{AlO}(\text{OH})$), and Diaspore (which has the same chemical composition as Boehmite), are the aluminium minerals found there. One of the primary sources of aluminium is bauxite, a mineral of aluminium. It usually contains Kaolinite, Goethite, Hematite, and trace amounts of Anatase (TiO_2) and Ilmenite (FeTiO_3 or $\text{FeO} \cdot \text{TiO}_2$) along with other minerals like Boehmite ($\gamma\text{-AlO}(\text{OH})$), Gibbsite ($\text{Al}(\text{OH})_3$), and Diaspore ($\alpha\text{-AlO}(\text{OH})$) (Liu et al., 2011). These bauxite ores have very different crystal formations from one another. **Production of Aluminum from Bauxite:** This industry is divided into 2 segments. The plants for obtaining alumina from bauxite ore, such plants are located near bauxite mines and plants for reduction of Alumina into Aluminum, such plants are located near the cheap source of electricity.

For producing 1 ton of aluminum, 6 tons of bauxite is required (which produces 2 tons of alumina). In this process, aluminium ore is treated with concentrated sodium hydroxide. Soluble sodium aluminate is formed which is filtered off. The filtrate on heating with water gives

BACKFILLING IN OPENCAST MINES USING RED MUD - AN INDIAN CASE STUDY

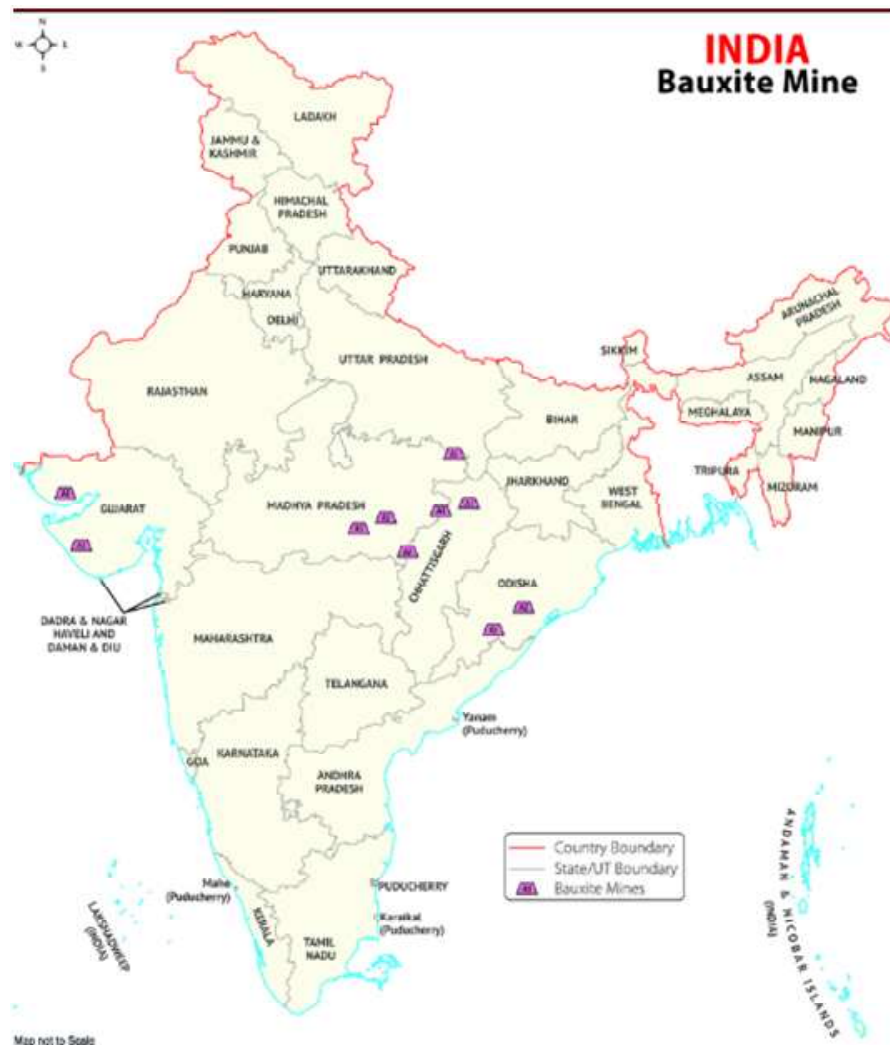


Figure 1 : Shows Bauxite deposits of India

aluminium hydroxide which gives alumina on strong heating.

Indian bauxite can be categorized into four different groups based on the mineralogy and order of preference:

- Gibbsite bauxite (Eastern ghats, Gujarat and coastal deposits of western India)
- Mixed Gibbsite- Boehmite bauxite (Boehmite < 10%, Diaspore < 2%; parts of Western Ghats and Gujarat deposits)
- Boehmite bauxites (Boehmite > 10 and Diaspore < 2%; Central Indian bauxite)
- Diasporic bauxites (Diaspore > 5%; J&K and some part of Central Indian and Gujarat deposits)

In this paper Red Mud generated from east coast bauxite occurring at Baphlimali Mines located in the Raygada-Nuapada districts of Odisha, of Utkal Alumina International has been discussed. The mined bauxite is refined at the Alumina plant down hill.

SPECIFICATION OF BAUXITE TO PRODUCE ALUMINA

To produce alumina (aluminum oxide) from bauxite ore through the Bayer process, certain specifications or characteristics of the bauxite are required. The quality of the bauxite plays a crucial role in determining the efficiency

and economics of the alumina production process. The key specifications of bauxite for alumina production include:

Chemical Composition: The bauxite must have a high content of aluminum oxide (Al₂O₃), typically ranging from 30% to 60% or more. Lower-quality bauxite with lower alumina content might require more extensive processing and result in higher production costs. Additionally, low levels of impurities like iron oxides (Fe₂O₃), silica (SiO₂), and titanium dioxide (TiO₂) are desirable to minimize the generation of red mud and increase the overall yield of alumina.

Reactive Silica: Reactive silica refers to the silica content that can easily dissolve during the Bayer process. High levels of reactive silica in bauxite can lead to silica scaling in the process, which reduces the efficiency and productivity of alumina production. Low reactive silica content is desirable to avoid these issues.

Particle Size: Bauxite should have a relatively fine particle size to ensure efficient digestion during the Bayer process. Smaller particle sizes increase the surface area for the chemical reactions to occur, leading to better alumina extraction.

Available Alumina: The available alumina content refers to the portion of alumina in bauxite that can be easily extracted using the Bayer process. Higher available alumina content is preferred to maximize the alumina yield and reduce the amount of unreactive alumina in the red mud.

Moisture Content: Low moisture content in bauxite is desirable to reduce energy consumption during the drying process before digestion.

Beneficiation: Bauxite beneficiation involves removing impurities and improving the quality of the ore before processing. This can include techniques such as washing, screening, and magnetic separation to enhance the alumina content and reduce impurities.

These specifications may vary depending on the specific alumina production process, the technology used, and the requirements of the alumina refinery. However, in general, bauxite with high alumina content, low impurities,

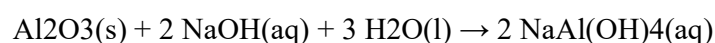
and favorable particle size distribution is preferred for efficient and cost-effective alumina production.

PRODUCTION OF ALUMINA FROM BAUXITE

Alumina (aluminum oxide) is produced from bauxite ore through a refining process known as the Bayer process. The Bayer process involves several steps to extract alumina from bauxite:

Crushing and Grinding: The mined bauxite ore is first crushed into smaller particles and then ground into a fine powder to increase its surface area for the subsequent extraction process.

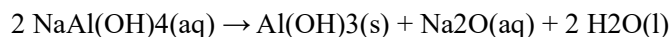
Digestion: The ground bauxite is mixed with a hot, concentrated solution of sodium hydroxide (NaOH) in high-pressure digesters. This step dissolves the alumina content of the bauxite into the sodium hydroxide solution while leaving behind impurities such as iron oxides, silica, and titanium dioxide. The chemical reaction is as follows:



Clarification and Precipitation: The sodium aluminate solution obtained from the digestion step is then cooled and allowed to settle to remove the remaining solid impurities. During this stage, any undissolved impurities settle as a red mud, and the clear sodium aluminate solution is separated.

Seed Addition: To initiate precipitation, "seed crystals" of aluminum hydroxide are added to the clear sodium aluminate solution. These seed crystals act as nuclei around which aluminum hydroxide molecules can form.

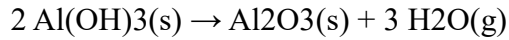
Precipitation: The addition of seed crystals triggers the precipitation of aluminum hydroxide from the sodium aluminate solution. The reaction can be represented as follows:



Separation and Washing: The precipitated aluminum hydroxide, which is now in the form of fine particles, is separated from the sodium aluminate solution using various separation techniques like filtration. The separated solids are then washed to remove any remaining sodium hydroxide.

BACKFILLING IN OPENCAST MINES USING RED MUD - AN INDIAN CASE STUDY

Calcination: The washed aluminum hydroxide precipitates are then heated at high temperatures (around 1000-1100°C) in rotary kilns or fluidized bed calciners to remove the chemically-bound water and convert the aluminum hydroxide into alumina



Final Product: The resulting product of this calcination step is alumina (aluminum oxide) in the form of a fine white powder. This alumina is the primary raw material used in the smelting of aluminum metal through

General Properties of Red mud presented in table 1

Table 1

Property	Range
Specific Gravity	2.6-3.1
pH Value	11.0-12.5
Pulp Density(g/cm ³)	1.1-1.3
Initial % of solids in Slurry	8.0-36.0
Settling Rate	1.0-3.0
% Solids after 24 hours	25-36
Particle size	<10mm 60-90 <1mm 10-20

electrolysis.

CHEMICAL & PHYSICAL COMPOSITION OF RED MUD

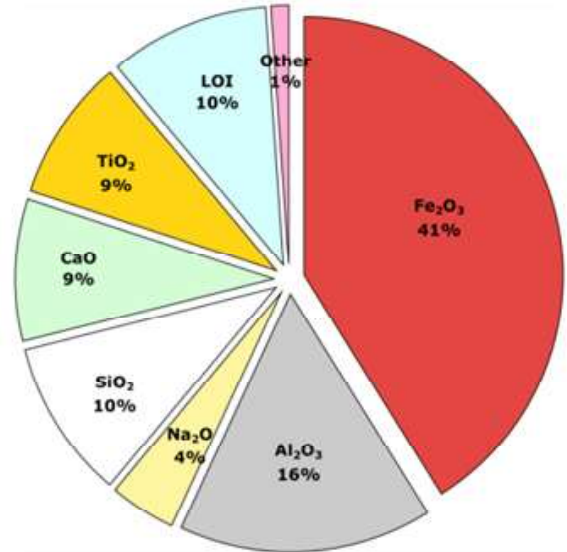


Figure 2: Chemical composition of red mud

Typical Chemical Composition of Red Mud presented in Table 2

Table 2

Major element	Conc.(wt%)	Minor element	Conc.(mg/kg)	Minor element	Conc.(mg/kg)
Fe	4.53-50.10	U	50-60	Mn	86
Al	4.42-16.06	Ga	60-80	Y	60-150
Si	2.16-14.86	V	730	Ni	31
Na	0.98-7.79	Zr	1230	Zn	20
Ca	0.39-16.72	Sc	60-120	Lantharides	0.1-1
Ti	0.98-5.34	Cr	497	-Th	20-30

Both free and bound forms of sodium can be found in red mud. Free sodium is the caustic soda that gets incorporated throughout the digesting process and stays with the red mud despite repeated washings. It is present in the entrained liquid of red mud slurry. The forms of free sodium include NaOH, Na₂CO₃, NaAlO₂, and others. These alkaline particles in red mud are responsible for the red mud's pH. The desilication phase used in the Bayer process to remove kaolinitic silica from bauxite is what causes the bound soda in the red mud. Bound soda exists as the sodalite complex, which can be written as 3(Na₂OAl₂O₃2SiO₂)Na₂X (X=CO₂²⁻, 2OH⁻, SO₄²⁻, 2Cl⁻).

About 20–25% of the sodium in red muds is free, with the remaining portion being sodalite complex. Regarding particle size distribution, red mud is a very fine substance. Red mud typically has particles that are smaller than 10 microns in size. Depending on how finely the bauxite is ground, the specific surface area (BET) of red mud ranges from 10 to 30 m²g⁻¹.

DISPOSAL OF RED MUD NEAR ALUMINA PLANT

The disposal of red mud, also known as bauxite residue, near an alumina plant is a critical aspect of alumina

production that requires careful consideration and management to minimize environmental impacts. Red mud is a highly alkaline and caustic material that can pose environmental risks if not handled properly. There are several common methods of red mud disposal near alumina plants:

Impoundments or Tailings Ponds: One common method of red mud disposal involves creating large impoundments or tailings ponds near the alumina plant. Red mud slurry is pumped into these ponds, where it settles, and the supernatant water is decanted. The settled red mud eventually dries, forming a solid waste deposit. Proper engineering and design of the ponds are crucial to prevent leakage and ensure stability.

Dry Mud Stacking: Dry stacking is another method where red mud is mechanically stacked in layers to form a dry, solid deposit. This approach reduces the need for large

ponds and can provide better environmental control. However, it requires more land area and appropriate compaction to ensure stability.



Figure.3.Source: CPCB



Figure 4: Mud Dewatering & Compaction



Figure 5: Dry Mud Stacking

Filter Press: Drum filters and plate and frame filter presses are used for filtration to recover caustic soda, which results in a more controllable bauxite residue by lowering the moisture level.

A typical press filter used for Red Mud is shown in Figure 6.



Figure.6

BACKFILLING IN OPENCAST MINES USING RED MUD - AN INDIAN CASE STUDY

Landfilling: Red mud can be placed in engineered landfills designed to prevent environmental contamination and control leachate. Landfilling is considered a safer method for long-term storage if the landfill is well-designed and properly managed.

Backfilling: In some cases, red mud may be used as a backfill material for mined-out areas or for reclamation and rehabilitation of disturbed lands near the alumina plant.

Current practices of management & disposal in Indian industries are presented in Table 3.

Table 3: Types of disposals in different industries in India

Sl.No.	Name of the Industry	Management and disposal practices
1.	M/s Hindalco Industries Ltd, Muri Jharkhand	Dry stacking of Red Mud started in June, 2002. Filter Press is used to increase solid content up to 75%. The filter cake i.e. the Red Mud from the filter press is collected into trucks through hoppers and hauled to the Red Mud disposal ponds. There are 4 Red Mud disposal ponds, of which 03 are exhausted.
2.	M/s Hindalco Industries Ltd, Renukoot, Uttar Pradesh	Both Drum Filters and Filter press (which caters to only 25% of total Red Mud generation) are used by the unit. There are 11 Red Mud disposal Ponds.
3.	M/s Utkal Alumina International Ltd., Odisha	There are 04 ponds, of which 3 are operational. The pond A was originally designed for wet storage and now being used for dry mud stacking since June, 2017. Filter Press is used and dry stacking of Red Mud is being followed.
4.	M/s Vedanta Limited, Lanjigarh, Odisha	High concentration slurry disposal of red was followed till 2013. After 2013, High Pressure Membrane Filtration Technology is being used for dry stacking of Red Mud. The filter-cake Red Mud is transferred to the pond via truck, spread in lifts to dry with a dozer and compacted with a sheep roller.
5.	M/s NALCO Ltd., Damanjodi, Odisha	Thickened Tailing Disposal (TTD) System are used wherein the Red Mud is discharged into a pond (RMP) at solid consistency varying between 54% - 60% at one point for having a sloped deposit. Installation of Filter Press is under Process.
6.	M/s BALCO Ltd., Korba, Chhattisgarh	The unit is non-operational since September, 2009. There are 07 Red Mud disposal ponds. One of the ponds has been reclaimed and plantation has been done. The remaining have been converted to ash dykes.
7.	M/s Hindalco Industries Ltd, Belgaum, Karnataka	Filter Press are used to reduce moisture content. Part of this Red Mud is sent to Cement industries for utilization and remaining is stored in Red Mud Ponds. There are 02 Red Mud disposal ponds available with the unit designed for wet ponding and the same got started used for the dry mud stacking.
8.	M/s MALCO Ltd., Tamil Nadu	The unit is non-operational since November, 2008. However, during its operational days, moisture of Red Mud was reduced using drum filters and hauled through trucks and stacked in the Red Mud Pond.

PROBLEMS ASSOCIATED WITH DISPOSAL OF RED MUD

Red mud disposal is associated with several significant environmental and safety challenges, which have been a concern for the aluminum industry and communities living near alumina refineries. Some of the problems associated with red mud disposal are as follows:

- **High alkalinity:** Red mud is highly alkaline due to the presence of sodium hydroxide in the Bayer process. When improperly managed, it can lead to soil and water alkalization, causing damage to ecosystems and aquatic life.
- **Land use and habitat destruction:** The large volumes of red mud generated by alumina refineries require vast land areas for disposal. This can result in habitat destruction and loss of valuable agricultural or forested land.
- **Risk of dam failures:** Red mud is often stored in large containment dams called tailings dams. The failure of these dams can lead to catastrophic environmental disasters, as seen in the Ajka alumina plant accident in Hungary in 2010, where a red mud dam failure resulted in the release of toxic slurry, causing significant environmental and human impacts.
- **Water contamination:** Improper containment or accidental spills of red mud can lead to water contamination. Red mud contains various heavy metals and other contaminants that can leach into the surrounding environment, polluting water bodies and affecting groundwater quality.
- **Airborne dust and pollution:** Red mud can generate airborne dust during transportation and disposal, which may contain hazardous materials. Prolonged exposure to this dust can be harmful to human health and can affect nearby communities and workers.
- **Long-term storage and management:** Red mud is a long-term waste product, and its disposal requires proper management and monitoring for decades or even centuries. This poses challenges in ensuring the continued stability and safety of containment structures.

- **Regulatory compliance:** Meeting regulatory standards for red mud disposal can be complex and costly. Compliance with environmental regulations and permits is crucial to avoid fines and penalties.
- **Public health concerns:** The potential for red mud to contaminate water sources and release harmful substances poses risks to the health of nearby communities and ecosystems.
- **Costs of disposal:** Proper disposal and management of red mud require significant financial resources. Finding economically viable and sustainable disposal solutions is a continual challenge for alumina refineries.

Efforts are ongoing to find alternative uses for red mud and develop innovative technologies to minimize its environmental impact. Recycling, reusing, and finding beneficial applications for red mud are essential steps in reducing the volume of waste generated and mitigating the problems associated with its disposal.

USES OF RED MUD

Utilization of Red mud: Efforts have been made to find beneficial uses for red mud, such as in the production of building materials, cement, and soil amendments. By finding valuable applications for red mud, the amount requiring disposal can be reduced.

RED MUD POND

Site selection to store Red Mud is influenced by - geology, hydrology, and proximity to water bodies. Regular monitoring of the disposal site, groundwater quality, and surface water is crucial to detect and address any potential environmental impacts. Proper engineering and containment measures must be implemented to prevent leakage, erosion, and other hazards. After the disposal facility's useful life, proper reclamation and rehabilitation should take place to restore the site's natural conditions.

It's important to note that the specific disposal method and management practices may vary based on local regulations, environmental considerations, and the technological capabilities of the alumina plant. Responsible management of red mud disposal is essential

BACKFILLING IN OPENCAST MINES USING RED MUD - AN INDIAN CASE STUDY

to minimize its environmental impact and ensure sustainable alumina production.

Mine site rehabilitation: Red mud can be used for land reclamation and mine site rehabilitation. Its use in re-vegetation programs can help restore the disturbed areas, stabilize slopes, and prevent erosion, thus promoting ecological recovery.

Dust suppression: The fine particle size and binding properties of red mud make it effective in controlling dust emissions from mine haul roads, stockpiles, and other areas prone to dust generation.

Acid mine drainage treatment: Red mud contains alkaline compounds, which can neutralize the acidity associated with acid mine drainage (AMD). When placed in or near areas affected by AMD, red mud can help mitigate its environmental impact.

Tailings management: Red mud can be used as a component in tailings dams to improve their stability and reduce seepage. Its addition can help bind the tailings particles, making the dam more secure and less prone to failures.

Backfilling in mine operations: Red mud can be mixed with other materials to create a suitable backfill material for underground mining operations. This approach provides a more environmentally friendly alternative to traditional backfill materials.

Water treatment: The adsorption properties of red mud can be harnessed for water treatment purposes, particularly in removing heavy metals and other contaminants from mine wastewater.

Erosion control: Red mud can be applied as a surface cover or mulch in erosion-prone areas to prevent soil loss and enhance soil stability.

Road construction and maintenance: Utilizing red mud in road construction and maintenance near mines can improve road durability, reduce maintenance costs, and provide a sustainable use for the waste material.

Metal recovery: Red mud contains residual metals, such as iron and titanium, which can be potentially recovered

and recycled, reducing the overall waste generated by the mining and refining processes.

Sustainable practices: Incorporating red mud into mine operations aligns with the principles of sustainable mining and waste management. By repurposing this byproduct, mines can reduce their environmental footprint and promote circular economy practices.

MINING VOIDS

A mining void refers to an area or space left behind after the extraction of minerals, ores, or other valuable materials through mining activities. When mining operations remove natural resources from the earth, they create voids or cavities in the ground, which can vary in size and shape depending on the mining method and the type of material extracted. Mining voids can occur both underground and on the surface.

THERE ARE TWO MAIN TYPES OF MINING VOIDS

Underground mining voids: These voids are typically created when minerals or ores are extracted from beneath the earth's surface. Underground mining methods, such as longwall mining, room and pillar mining, and block caving, can leave extensive voids and tunnels underground.

Surface mining voids: Surface mining involves removing minerals or ores from large open pits or quarries. As the material is extracted, significant holes or depressions are formed on the surface, leaving behind surface mining voids.



Figure 7: Source: AWA

Mining voids can present various challenges and risks, including:

Subsidence: The removal of material from underground can cause the ground above to collapse or subside, leading to surface deformations and potential damage to buildings and infrastructure.

Water accumulation: Mining voids may fill with water, forming lakes or ponds. If not managed properly, these water bodies can become sources of contamination and pose safety risks.

Environmental impacts: Mining voids can disrupt natural habitats and ecosystems, affecting flora and fauna in the area. They can also alter groundwater flow patterns, leading to changes in water quality and availability.

Safety hazards: Unstable ground in and around mining voids can pose risks to human safety, especially in areas where voids are close to residential or industrial areas.

Limitations on land use: Mining voids can restrict or limit future land use options, making it challenging to develop or utilize the land for other purposes after mining operations have ceased.

Statutory provisions governing use of Red Mud - Backfilling of Mining Voids as per MMDR Act & MCDR

The Mineral Conservation and Development Rules (MCDR), 2017, are part of the Mines and Minerals (Development and Regulation) Act (MMDR Act), 1957, which governs the regulation of mining activities in India. The MCDR provides guidelines and regulations for various aspects of mining, including backfilling of mining voids. Backfilling is the practice of filling the voids created by mining activities with suitable materials to restore the land and ensure stability. Here are some key points regarding backfilling of mining voids as per the MMDR Act and MCDR:

1. **Backfilling as a requirement:** The MCDR mandates that mine operators must backfill the voids created during mining operations to the extent possible. The idea is to restore the land to a safe and stable condition after the extraction of minerals.
2. **Backfill materials:** The rules specify that the backfill materials should be non-toxic, non-hazardous, and

not detrimental to the environment. These materials can include waste rock from mining operations, fly ash, mill tailings, and other suitable materials approved by the regulatory authorities.

3. **Environmental clearance:** The backfilling plan and the choice of materials must be included in the Mine Closure Plan, which is submitted for environmental clearance before the start of mining activities.
4. **Backfilling during the operation:** In underground mining operations, progressive backfilling is encouraged to maintain the stability of the mine voids as mining progresses. This practice helps to minimize the risk of subsidence and ensures the safety of miners and surrounding areas.
5. **Surface mining:** In surface mining operations, backfilling may be required to reclaim and restore the land after mining is completed. Backfilling can help to shape the land, reduce erosion, and facilitate re-vegetation.
6. **Monitoring and compliance:** Mine operators are required to monitor the backfilled areas and ensure that the backfill materials remain stable and do not pose any environmental hazards.
7. **Financial assurance:** Mine operators are required to provide financial assurances, such as environmental bonds or funds, to cover the costs of mine closure and land reclamation, including backfilling activities.
8. **Community engagement:** The MCDR emphasizes the importance of involving local communities in mine closure and backfilling plans to ensure their concerns and traditional rights are considered.

It is essential for mining companies to adhere to the guidelines provided by the MMDR Act and MCDR to ensure responsible mining practices and minimize the environmental impacts of mining activities. Proper backfilling of mining voids is a crucial aspect of mine closure and land reclamation, and it plays a significant role in restoring the affected areas to a safe and sustainable condition.

The Ministry of Environment, Forest, and Climate Change (MoEFCC) in India has issued guidelines and notifications related to the use and management of red mud, also known as bauxite residue. Below are some of the key guidelines issued by MoEFCC in the context of red mud:

BACKFILLING IN OPENCAST MINES USING RED MUD - AN INDIAN CASE STUDY

- Guidelines for Safe Disposal of Red Mud:** The MoEFCC has issued guidelines to ensure the safe disposal of red mud to prevent environmental pollution and harm to human health. These guidelines may include recommendations for storage, containment, and monitoring of red mud disposal sites.
- Guidelines for Utilization of Red Mud in Construction:** MoEFCC has provided guidelines for the beneficial use of red mud in construction projects, such as in road construction, embankments, and building materials. These guidelines aim to promote sustainable practices and reduce the environmental impact of waste disposal.
- Environmental Clearance:** Mining and alumina refining projects that generate red mud are required to obtain environmental clearance from the MoEFCC. The clearance process includes an assessment of the environmental impact of the project and measures to mitigate potential adverse effects, including those related to red mud management.
- Hazardous and Other Wastes (Management and Transboundary Movement) Rules, 2016:** Red mud is considered an industrial waste, and its management is governed by the Hazardous and Other Wastes Rules. The MoEFCC provides guidelines for the proper handling, storage, and transportation of red mud under these rules.

CASE STUDY

In order to study the use of red mud Baphlimali Bauxite Mine of M/S Utkal Alumina International was selected. This mine is the captive mine of the Alumina Plant located at a distance of about 30 km from the mine. R-O-M bauxite is crushed by the crushing plant is transported to the alumina plant by a conveyor system of 18 km Long.

Location

The mine is located in Paikkupakhai, Karanjakupakhal, Dhuturapass, Danadabad & Chandragiri village of Rayagada district and Durumusi, Suryagada&Kendumundi of Kalahandi district in Odisha state.

The mine falls in the Survey of India Topo sheet No. 65 I/ 15 between latitude 19°19'22.78234" to 19°22'11.40057" N and longitude 82°56'17.25017" to 82°59'06.92518" E.

SALIENT FEATURES OF THE MINE

Utkal Alumina International Limited (UAIL), is a 100 per cent subsidiary of Hindalco Industries Limited, a metals flagship of Aditya Birla Group.

A leading alumina refinery, Utkal operates in the Rayagada district of Odisha. It comprises a 2.12MTPA alumina refinery, captive Baphlimali bauxite mines of 8MTPA with valid lease title up to February 2048, and a captive co-generation power plant of 90MW along with a 5MW solar power plant.



Figure 8: Area Map of Baphlimali Mining Lease



Figure 9: Mine working

Utkal was originally conceptualized in 1992-93 to set up an alumina refinery with captive bauxite mines by four reputed corporate groups – Alcan, INDAL, Tata and Norsk Hydro Aluminium of Norway.

INDAL was merged with Hindalco in the year 2004 and subsequently UAIL became a 100 per cent subsidiary of Hindalco in FY 2008.

Utkal is a world-class refinery with state-of-the-art technology from the world's acclaimed technology supplier, Rio-Tinto-Alcan. Utkal has the best quality bauxite as its input, and an environment-friendly logistics network for bauxite, other raw materials and product alumina through conveyors and railway networks. The bauxite for UAIL is sourced from Baphlimali mines and travels over an 18km Long Distance Conveyor (LDC), which is one-of-a-kind in the world. UAIL enjoys the global leadership position in terms of product quality, energy consumption and cost per ton.

Utkal caters to 70 per cent of Hindalco's smelter's alumina requirement and supplies to other domestic and international market. The high purity alumina supplied by Utkal enables our new age smelters to produce niche aluminium metal catering to sectors like aviation and space, defense, food & beverage, transport etc. Initially Utkal's greenfield plant was commissioned with a capacity of 1.5MTPA in 2013-14. This plant was expanded to 2.12MTPA and commissioned in August 2021.

Year after year, Utkal is surpassing its own record in terms of production, efficiencies, customer expectations, societal stewardship and creating a new benchmark.

As a responsible corporate citizen, Utkal is committed to socio-economic well-being and transforming the lives in the tribal hinterland. Utkal is relentlessly working to improve the Human Development Index of our community through various CSR, CR & sustainability initiatives in 232 villages of 25 gram panchayats of Odisha. Utkal is touching the lives of more than 201,000 people through its five pillars of interventions - education, healthcare, sustainable livelihood, rural infrastructure and addressing the issues of their socio-economic concern. Utkal's unique multi-stakeholder-based initiatives are in line with the Sustainable Developmental Goal of United Nations 2030. -(Photo of the mine with Geotag)

Geology of the mine:The plateau top is generally flat and the elevation in the M.L area varies from 990m to 1094m. The highest point on the plateau is at 1094 meter above mean sea level.

Baphlimali bauxite deposit in the M.L area belongs to east-coast bauxite where the lateralization was developed at the expense of Gneisses and Schists. The dominant rock assemblage in the region comprises Khondalites and its variants. These are high grade metasediments of Argillaceous, Arenaceous and Calcareous nature. The Bauxite deposit is a weathering product of Precambrian Khondalite group, a high-grade meta-sediment Gneiss, comprising chiefly of Quartz, Garnet, Feldspar-Sillimanite with or without Graphite. This M.L area is a part of Baphlimali hill which is characterized by a NE-SW trending Bauxite capping surrounded by Khondalite on the slopes. Bauxite forms an integral part of the lateritic profile which is derived by the in-situ chemical weathering of the khondalite. It occurs as a gently rolling or near flat blanket capping the steeply dipping khondalites. The boundary of

BACKFILLING IN OPENCAST MINES USING RED MUD - AN INDIAN CASE STUDY

the bauxite capping is marked at scarp faces. In general, the foliation of khondalite strikes due NNE – SSW and dips at 400 to 800 towards ESE direction. Khondalite is the parent rock of bauxite which occurs at the base of

bauxite profile. It is heterogeneous in mineral composition and essentially Quartz-Orthoclase, Garnet Sillimanite Gneiss. Most of it is rich in Feldspar, Sillimanite and Garnet. Partially Lateritised Khondalite (PLK) / Partially Kaolinised Khondalite (PKK) lies below the Bauxite.

Production capacity is presented in table 4

Table 4

	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22
ROM Bauxite (Mill Tonnes)	4528000	4729000	4790000	4927000	5297000	5299830	5998340
Alumina Produced (Mill Tonnes)	1402100	1499600	1499700	1553600	1667495	1559209	1747916
Quantity of Red Mud generated	1914000	1974000	2049000	2082000	2232705	2055236	2408045

TRANSPORTATION

Once red mud is generated, it needs to be transported from the refining facility to storage or disposal sites following MoEFCC norms. In Utkal alumina International method used for transporting red mud is by trucks and pipe line . Red mud is loaded onto trucks for distance of about 11 km from the plant to storage facility.



Figure 10: Truck Yard near Red mud Pond

STORAGE

Red mud is the residue generated during manufacture of alumina having the leachable caustic content in disposed liquor <10 gpl expressed as Na_2CO_3 in slurry condition with 40-60% water and solids .The water is being removed by pressure filter and in semi-dry condition (78% of solids) disposed in impervious pond known as Red mud Pond. The entire red mud pond is divided into 4 parts ,Pond A B C & D.Out of these pond A & B are meant for Mud Storage

.Pond C is meant for collection of Supernatant Liquor (SNL) from the pressure filter and mud storage pond A & B . Pond D is meant for freshwater emergency storage. The 1/3rdof the pond A mud storage dam is lined with Clay along with 1.5mm thick single layer HDPE liner. Pond D is also lined with Clay along with 1.5mm thick single layer HDPE liner & is currently having fresh water in it.

The Mud storage dam also has a leachate drain under the HDPE liners and connected to the lowest point out

ADITYA JHA

side the dyke in a collection pipe and the leachate water is being pumped back to the pond C for storage, Fixed rain gun water sprinkling system has been provided at the red mud pond to prevent dust from red mud pond area. In addition to this, water tankers are being deployed for water sprinkling on roads of the red mud pond.

Currently in Utkal Alumina International Ltd. Utilization of red mud is carried out for backfilling of mining voids & for cement industries. In Figure 10 below shows the backfilling of red mud in mining voids which is covered by tarpaulin sheets to protect it from rain water to avoid contamination of soil and ground water.



Figure 11: Stacked Red mud



Figure 12: Red Mud Pond

BACKFILLING IN OPENCAST MINES USING RED MUD - AN INDIAN CASE STUDY



Figure 13: Red Mud Ponds



Figure 14: Red Mud dewatering Pond

CHEMICAL COMPOSITION OF RED MUD OF UTKAL ALUMINA INTERNATIONAL LIMITED

Red mud is alkaline in nature and is having pH of about 11 to 12.5. The typical chemical composition of the Red mud is given in table below:

LOI%	TA%	THA%	T-SiO ₂	Fe ₂ O ₃	TiO ₂	Na ₂ O	P ₂ O ₅	V ₂ O ₅	CaO
6.93	13.54	4.33	6.35	61.31	3.94	2.87	0.22	0.11	1.84

At AKS University the Red Mud samples were tested for their chemical composition as well as pH. The investigation carried out by Chaurey (2018) and his team, had investigated the relationship between soil micro flora and soil pH. From the soil samples microbial load was determined by serial dilution method. pH of culture media within 7- 11 for the isolation of bacteria.

STORAGE OF RED MUD AT THE SITE OF DISPOSAL

Red mud is stored in ponds which are lined by thick walls on the periphery for avoidance of overflow and ponds are also lined with liners for separating it from the ground soil to avoid contamination of soil and underground water. Red mud is highly alkaline, which can result in increased pH levels when used in mining voids. Adequate care is taken to test the samples in respect of their chemical composition and remedial actions to make them safe for disposal.



Figure 15: Red mud Storage facility

CONCLUSION

Red Mud disposal, storage, transport etc cause sever impact on the land area as well as the general environment. The efforts made by regulators, research

institutions, R&D establishment of Aluminium companies is quite encouraging. While Utkal Alumina is using red mud for cement making, other units in India need to increase efforts in this direction.

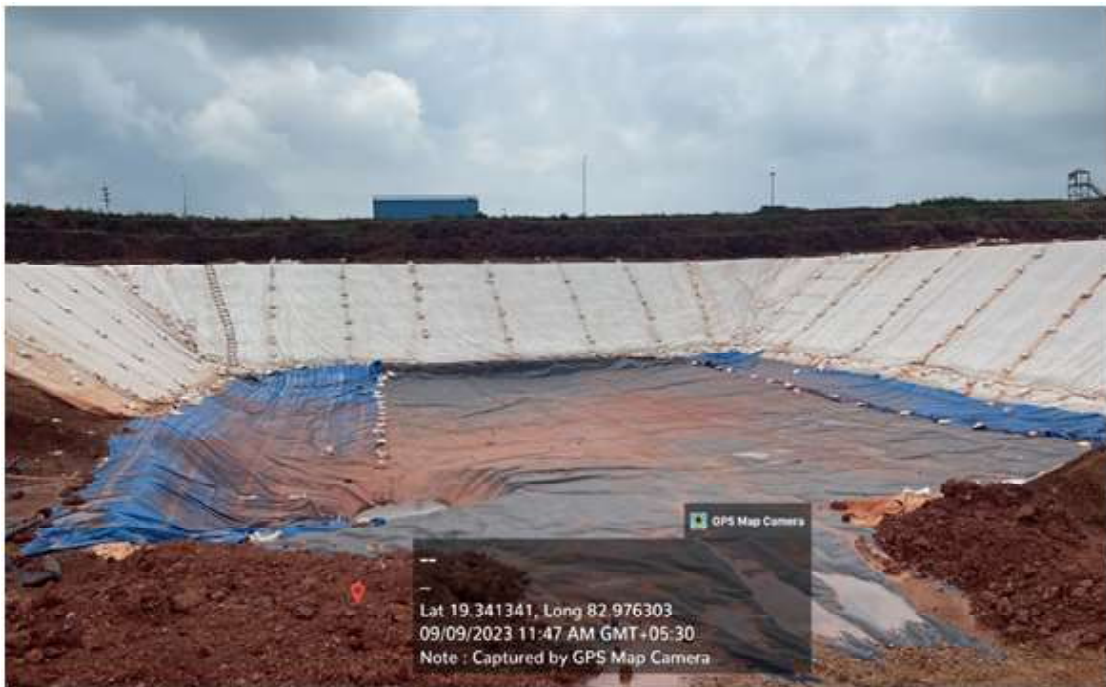


Figure 16: Backfilled mine void by Red mud

BACKFILLING IN OPENCAST MINES USING RED MUD - AN INDIAN CASE STUDY

SELECTED REFERENCES

Amritphale SS, et al(2005), Development of Xray shielding materials utilizing red mud. ICSOBA-2005, 16th International Symposium on Status of Bauxite, Alumina and Aluminium Industry and Future at Nagpur, India, 28-30 Nov.2005:pp.350-357.

Hua.Y et al. (2017)The use of red mud as an immobilizer for metal/metalloid-contaminated soil, Journal of Hazardous Materials, Volume 325, 5 March 2017, Pages 17-30

Mineral Conservation and Development Rules, 2017

National Mineral Policy, 1999.

Patangia, J. et al (2023), Study on the utilization of red mud (bauxite waste) as a supplementary cementitious

material: Pathway to attaining sustainable development goals, <https://doi.org/10.1016/j.conbuildmat.2023.131005>, Journal: Construction and Building Materials, 2023, p. 131005, Elsevier BV

Rai, Suchita. et al. (2018) Potential application of red mud in vegetation. National Conference on "Waste to Wealth in Mineral & Metallurgical Industries, WMMI-2018, Bhubaneswar.

Rai,S. et al (2021) Utilization of Aluminum Industry Solid Waste (Red Mud/Bauxite "Residue) in Pollution Control, Earth and Environmental Sciences Library book series"(EESL),pp 149-160,

Satapathy A et al (1007), Red mud: A potential coating material, ENVICON 2007, National seminar on environmental concern and remedies in Alumina Industry at NALCO, Daman Jodi, India 27-28th Jan., 2007: 139-142.

Assessment of Air Quality and its Effects on Vegetation and Human Health Proximate to J.P. Cement Plant Rewa M.P.

Mahendra Kumar Tiwari* R.M.Mishra** R.S. Parihar***

ABSTRACT

Air pollution is the process which the substances and the energy forms are not present in normal atmospheric composition reach the atmosphere, or are present but in much lower concentrations. Air pollution is the introduction of chemicals, particulate matter, or biological materials that cause harm or discomfort to humans or other living organisms, or cause damage to the natural environment or built environment, into the atmosphere. Atmospheric particulate matter is a mixture of diverse elements. Deposition of particulate matter to vegetated surfaces depends on the size distribution of these particles and, to a lesser extent, on the chemistry. Effects of particulate matter on vegetation may be associated with the reduction in light required for photosynthesis and an increase in leaf temperature due to changed surface optical properties. Changes in energy exchange are more important than the diffusion of gases into and out of leaves which is influenced by dust load, color and particle size. Alkaline dust materials may cause leaf surface injury while other materials may be taken up across the cuticle. Air pollution has both acute and chronic effects on human health, affecting a number of different systems and organs. It ranges from minor upper respiratory irritation to chronic respiratory and heart disease, lung cancer, acute respiratory infections in children and chronic bronchitis in adults, aggravating pre-existing heart and lung disease, or asthmatic attacks. In addition, short- and long-term exposures have also been linked with premature mortality and reduced life expectancy. A study on ambient air quality at J.P. Cement Plant's rural areas and its possible effects on selected plants and human health have been undertaken, which may be helpful to bring out possible control measures.

Key words: Air pollution, ambient air quality, human health, particulate matter, vegetation.

INTRODUCTION

The modernization and industrialization of developing countries has led to the increased use of fossil fuels and their derivatives. As such, developing countries are confronted with the great challenge of controlling the atmospheric pollution, especially in the rapidly growing urban centers. Air pollution is an important problem in industrial areas which may have an adverse effect on the health of the population. Air pollution is due to the discharge of toxic fumes, gases, smoke and dusts into the atmosphere (Park and Park, 1985).

Concern about air pollution in urban regions is receiving increasingly importance worldwide, especially pollution by gaseous and particulate trace metals (Azad and Kitada,

*Prof. and Head, Deptt. of Environmental Sc., AKS University Satna

**Prof., School of Environmental Biology, APS University Rewa M.P.

***Regional Officer, Regional Office MP Pollution Control Board Satna M.P.

Corresponding Author: tiwarimahendrakumar@gmail.com

1998; Salam et al., 2003; Begum et al., 2004; and Cachier et al., 2005). A great deal of attention has focused on particulate matter (PM) pollution, due to their severe health effects, especially fine particles. Several epidemiological studies have indicated a strong association between elevated concentrations of inhalable particles (PM₁₀ and PM_{2.5}) and increased mortality and morbidity (Perez and Reyes, 2002; Lin and Lee, 2004; Namdeo and Bell, 2005). Particulate matter pollution in the atmosphere primarily consists of micron and sub-micron particles from anthropogenic and natural sources. The characterization of fine particles has become an important priority of regulators, and researchers due to their potential impact on health, climate, global warming, and long-range transport (Dockery et al., 1993; IPCC, 2001).

The typical gaseous emissions to air from cement manufacturing plants include nitrogen oxide (NO_x), Sulphur dioxide (SO₂), carbon oxides (CO & CO₂) and dust (Pregger and Friedrich, 2009; Kampa and Castanas,

2008). The dust escaping from cement factories is often transported by wind and deposited in areas close and far away from the factory. These include agricultural lands, natural vegetation, towns and villages, such depositions of particulate matter and other pollutants interfere with normal metabolic activities of plants, causing direct injury and impairment of growth and quality and may ultimately lead to decrease in plant yield (Ediagbonya et al., 2013; Prajapati, 2012). The cement kiln dust, containing oxides of calcium, potassium and sodium is a common air pollutant affecting plants in various ways i.e. cement dust and cement crust on leaves plug stomata and interrupt absorption of light and diffusion of gases, lowering starch formation, reducing fruit setting (Lerman, 1972; Shrivastava, 1999), inducing premature leaf fall (Czaja, 1962; Tiwari et al., 2011) and leading to stunted growth (Darley, 1966). Besides causing suppression of plant growth, cement dust induces the change in the physico-chemical properties of soil, which are generally unfavorable to plant growth (Parthasarthy et al., 1975; Singh and Rao, 1978).

MATERIAL AND METHODS

Study area

The study area is bounded between 24°28'24" to 24°39'11" north latitude and 81°05'46" and 81°17'23" east longitude (Approx). Jaypee cement limited is operating a 2.8 MTPA cement manufacturing plant at Jaypee nagar which is 15 km from Rewa town. The study site Naubasta village which is close to from cement plant is situated about 1.5km towards NE direction from the source of emission. The population of village is 2046 and has surface area of 532.67 hectare. The annual rainfall of this region is 1139.15 mms and average maximum and minimum temperature are 36.80C and 120C respectively. More than 90% annual rainfall occurs during the monsoon months. The mean wind speed in the study area is varied between 0-15km/hrs.

Apparatus and Procedure

Respirable Dust Sampler, Envirotech model APM- 460 BL-441 is employed to monitor the pollutants. The sampling duration was 8 hours period operated at an average flow rate of 1.5 LPM. Monitoring is carried out once in a month at four sampling sites viz; J P Nagar, Main gate, Naubasta colony and Chijwar for one year

(2010-2011). NEERI and CPCB recommended methods are followed to estimate air pollutants concentrations. Amount of Respirable Particulate Matter (RPM) was collected in the glass fabric filter paper whereas suspended particulate Matter (SPM) was collected on dust cup. Samples for determination of SO₂ and NO_x were collected by bubbling air samples in the appropriate absorbing media in impingers at flow rate of 1.5 LPM. These samples were analyzed for SO₂ and NO_x spectrophotometrically. Impacts of air pollution on human health data were collected as per survey schedule.

RESULTS AND DISCUSSION

A summarized data of average concentrations of air pollutants such as Suspended Particulate Matter, Respirable particulate Matter. Sulphur dioxide and Nitrogen oxides for three seasons of the study period are given in Table 2. The estimated SPM concentrations in the ambient air of four sampling sites varied between 275.28 µg/m³ to 340.15µg/m³, 210.40 µg /m³ to 264.94 µg/m³ and 150.84 µg /m³ to 194.71µg/m³ during winter, summer and rainy months respectively, Respirable particulate Matter (RPM) were found in the range of 105.15 µg/m³ to 132.28 µg/m³, 92.64.64 µg/m³ to 105.19µg /m³ and 78.49 µg / m³ to 83.48. µg/m³ during winter, summer and rainy months respectively. SO₂ values varied between 18.62 µg/m³ to 24.48 µg/m³, 13.49 µg/m³ to 18.74 µg/m³, and 7.54 µg/m³ to 8.98 µg/m³ at four sampling sites during winter, summer and monsoon months respectively. All the sampling sites exhibited NO_x concentrations in the range of 22.28 µg/m³ to 30.75 µg/m³ (Winter), 19.86 µg/m³ to 22.68 µg/m³ (summer) and 10.34 µg/m³ to 18.48 µg/m³ (rainy months). Out of four sampling sites, the ambient air of Chijwar and Naubasta colony showed maximum and minimum concentrations of SPM, RPM. SO₂ and NO_x concentrations.

The average concentration of SPM and RPM in the ambient air of studies sites are above the permissible limit (200µg/m³ for SPM, 100 µg/m³ for RPM) for residential and rural uses. Whereas, the gaseous pollutants (SO₂ and NO_x) are well within permissible limit (80µg/m³) prescribed by CPCB, New Delhi for residential and rural uses: Results observed in the present study particularly for SPM are in agreement with the monitoring results obtained around different cement plants of the country (Baenrjee and Pandey, 1989; Agrawal and

ASSESSMENT OF AIR QUALITY AND ITS EFFECTS ON VEGETATION AND HUMAN HEALTH PROXIMATE TO J.P. CEMENT PLANT REWA M.P.

Khanam 1989; Shrivastava, 1999; Chandrasekharan et al; 1996).

Human health diseases: As the most common route for pollutants to enter the human body is by inhalation, the most common effect of air pollution is damage to the respiratory system. Exposure to air pollutants can causing respiratory diseases (such as lung cancer, tuberculosis, asthma, bronchitis and emphysema), gastrointestinal diseases, blood pressure diseases, dental diseases, eye diseases, skin diseases and other diseases may also suffer when the air is polluted. A questionnaire based survey was conducted to get the statistics for incidence of various diseases among the people of sampling sites. Survey was conducted for general incidence of various diseases among the people of five sampling sites. Table-Represent the percentage of person suffering from respiratory diseases was found in the range of 28.35 % to 52.54 % at all sampling sites, The estimated gastrointestinal percentage at five sampling sites varied between 20.07 % to 40.65%, blood pressure diseases was found in the range of 13.47% to 33.61% at the sampling sites, dental diseases varied between 15.99% to 28.00% at five sampling sites. All the sampling sites exhibited eye diseases in the range of 13.80% to 25.03%, out of five sampling sites skin diseases found in the range between 13.44% to 35.59% whereas other diseases found in the range of 9.76% to 23.10% at all sampling sites during survey period. Out of five sampling sites, showed maximum percentage of person suffering from respiratory disease which is higher at Main Gate (52.54%) to be followed by J P nagar (46.90%), Naubasta colony (46.32%), Chijwar (42.27%) and Rewa road (28.35%). A health effect of SPM in humans depends on particle size, concentrations and exposure time. Exposure to 200 $\mu\text{g}/\text{m}^3$ of particulate matter can cause upper respiratory diseases and 294-470 $\mu\text{g}/\text{m}^3$ depress immune function in children. Our results confirmed what has already been argued in the literature. The analysis certifies the harmful effects of air pollution and weather parameters mostly SO_2 was positively correlated with health admission for every additional 100 $\mu\text{g}/\text{m}^3$ and +25 $\mu\text{gr}/\text{m}^3$, respectively. Significant also seemed to be the results for other pollutants, such as NO_2 and CO. In other studies NO_2 was positively associated with cardiovascular admissions and death increased risk ranging from 14% (admissions for every 10 PPhm) to 1% (death for every 10 $\mu\text{gr}/\text{m}^3$). International studies have conformed association between elevated levels of particulate air pollution and

increase in respiratory symptoms such as cough, shortness of breath, wheezing and asthma attacks. The resulting exposure to cement dust has led to impairment of respiration and a prevalence of respiratory symptoms amongst workers culminating in what has been described as a "Cement factory lung disease". The severity of the impairment of respiratory function has been shown to depend on years of exposure.

CONCLUSION

The main environmental issue associated with cement production is the emission of pollutants (SPM, SO_2 and NO_x) in the atmosphere. These air pollutants have long been associated with prevalence of various diseases in human beings. Results revealed higher concentrations of SPM in the ambient air of all the selected villages than permissible limit of 200 $\mu\text{g}/\text{m}^3$, prescribed by central Pollution Control Board, New Delhi. Contrarily, the ambient air SO_2 and NO_x concentration have been estimated below the permissible limit of 80 $\mu\text{g}/\text{m}^3$, Prescribed by CPCB, New Delhi. Result indicated higher SPM, SO_2 and NO_x concentrations in the ambient air during winter months to be followed by summer and monsoon months. The human populations of all selected sites were surveyed for prevalence of various diseases such respiratory diseases, gastrointestinal diseases, blood pressure, dental diseases, eye diseases, skin diseases and other diseases. Result indicated maximum people of all selected sites suffering with respiratory diseases than other problems.

Table (1): Major sources of the main pollutants of the cement manufacturing building

Emission	Specific pollutant	Source classification	Location
Gas	SO_2	Point sources	Raw mill and kiln stack exit
	NO_x		
	CO		
Dust	TSP, PM_{10} and	Point sources	Clinker cooler and cement mill stacks exit
	$\text{PM}_{2.5}$	Volume sources	Outlets through dust control devices

Table2: Seasonal variation of air pollutants in the ambient air of four sampling sites during 2010

S/N	Sampling sites	SPM ($\mu\text{g}/\text{m}^3$)			RPM ($\mu\text{g}/\text{m}^3$)			SO ₂ ($\mu\text{g}/\text{m}^3$)			NO _x ($\mu\text{g}/\text{m}^3$)		
		W	S	R	W	S	R	W	S	R	W	S	R
1	J.P nagar	310.41	262.82	185.46	118.43	98.75	80.8	21.84	15.98	7.54	24.32	18.95	16.48
2	Main gate	321.54	248.80	190.34	120.41	104.85	80.34	22.56	17.81	8.32	29.36	21.64	18.92
3	Naubastacolony	257.28	210.40	150.84	105.15	92.64	78.49	18.62	13.49	7.86	22.28	19.86	10.34
4	Chijwar	340.15	264.94	194.71	132.38	105.19	83.48	24.48	18.74	8.98	30.75	22.68	18.48

W= Winter, S=Summer, R=Rainy

Table 3: Annual concentration of different air pollutants in the ambient air of four sampling sites

S/N	Samling Site	SPM ($\mu\text{g}/\text{m}^3$)	RPM($\mu\text{g}/\text{m}^3$)	SO ₂ ($\mu\text{g}/\text{m}^3$)	NO _x ($\mu\text{g}/\text{m}^3$)
1	J P Nagar	252.89	99.32	15.12	19.91
2	Main gate	253.56	101.86	16.23	23.04
3	Naubasta colony	212.17	92.09	13.32	17.49
4	Chijwar	166.60	107.01	17.40	23.97
5	Average	246.30	100.07	15.52	21.10

Table 4. National ambient air quality standards (NAAQS) CPCB.

area	average	($\mu\text{g}/\text{m}^3$)	area ₃ ($\mu\text{g}/\text{m}^3$)	areas ($\mu\text{g}/\text{m}^3$)	measurement
Suspended Particulate Matter (SPM)	Annual*	70	360	140	High volume sampler
Respirable particulate matter (RSPM)	Annual*	50	120	60	High volume sampler
	24 h**	75	15	100	
Sulphur dioxide (SO ₂)	Annual*	15	80	60	West and Gaeke
	24 h**	30	120	80	Method.
Oxides of nitrogen (NO _x)	Annual*	15	80	60	Jacob and Hochheiser
	24 h**	30	120	80	Modified method.

*Annual arithmetic mean of minimum 104 measurements in a year taken twice a week 24 hourly at uniform interval. **24 hourly/8 hourly values should be met 98% of the time in a year. However, 2% of the time, it may exceed but not on two consecutive days.

**ASSESSMENT OF AIR QUALITY AND ITS EFFECTS ON VEGETATION AND HUMAN HEALTH
PROXIMATE TO J.P. CEMENT PLANT REWA M.P.**

Table -5 Percentage of air pollution oriented diseases among the people of sampling sites.

Sl. No.	Diseases	Sampling sites				
		J P Nagar	Main Gate	Naubasta colony	Chijwar	Rewa road
1.	Respiratory diseases	46.90	52.54	46.32	42.27	28.35
2.	Gastrointestinal diseases	35.46	40.65	31.43	26.31	20.07
3.	Blood pressure	33.61	18.19	28.16	26.48	13.47
4.	Dental diseases	16.65	15.99	28.00	18.60	16.14
5.	Eye diseases	24.23	13.80	22.73	17.31	25.03
6.	Skin diseases	35.59	17.56	17.03	21.09	13.44
7.	Other diseases	23.10	17.02	13.24	15.86	9.76

REFERENCE

- ♦ Agrawal, M. and Khanam, N. (1997) Variation in concentrations of particulate matter around a cement factory. *Ind. J. Environ. Health*, 39(2):97-102.
- ♦ Alakija W., Iyawe V.I., Jarikre L.N. and Chiwuzie J.C., Ventilatory function of workers at Okpella cement factory in Nigeria, *West Afr. J Med.*, 9, 187-192 (1990)
- ♦ Al-Neaimi Y.I., Gomes J. and Lloyd O.L., Respiratory illnesses and ventilatory function among workers at a cement factory in a rapidly developing country, *Occup Med.*, 51(6), 367-373 (2001)
- ♦ Azad, A.K. and Kitada, T. 1998. Characteristics of the air pollution in the city of Dhaka, Bangladesh in winter. *Atmos. Environ.*, 32: 1991-2005
- ♦ Banerjee, D and Pandey, G.S. (1989). Micropollutant particulates in the ambient air of a cement plant. *Intern. J. Environ Anal. Chem*, 35:169-174.
- ♦ Begum, B.A., Kim, E., Biswas, S.K. and Hopk, P.K. 2004. Investigation of sources of atmospheric aerosol at urban and semi urban in Bangladesh. *Atmos. Environ.*, (38): 3025-3038.
- ♦ Cachier, H., Aulagnier, F., Sarda, R., Gautier, F., Masclet, P. and Besombes, J.L. 2005. The ESCOMPTE experiment: 108 *Air. Qual. Atmos. Health*, (1): 101-109.
- ♦ Chandrasekharan, G.E., Ravichandran, C. and Mohan, C.A. (1998). A short report on ambient air quality in the vicinity of a cement plant at Dalmiapuram. *Indian Journal of Environmental protection* 18 (1): 7-9
- ♦ Czaja AT. 1962. Uber das problem der zementstaubwirkungen auf Pflanzen von zementofenstaub auf pflanzen, *Angewandte Botanik*, 40: 106-120
- ♦ Dockery, D.W. and Pope, C.A. 1994. Acute respiratory effects of particulate air pollution. *Animal Review of Public Health* 1(5):
- ♦ Ediagbonya TF, Ukpebor EE, Okiemien FE. 2013. Spatio-temporal distribution of inhalable and respirable particulate matter in rural atmosphere of Nigeria. *Environmental Skeptics and Critics*, 2(1): 20-29
- ♦ IPCC (International Panel on Climate Change) 2001. The third assessment report of working group I of the intergovernmental panel on climate change. Technical summary. IPCC Shanghai.
- ♦ Kampa M, Castanas E. 2008. Human health effect of air pollution, *Environmental Pollution*, 151: 362-367
- ♦ Lerman S. 1972. Cement kiln dust and the bean plant (*Phaseolus vulgaris* L. Black valentioe Var.): In depth investigations into plant morphology, physiology and

pathology. PhD Dissertation, University of California, Riverside, USA

- ♦ Linn W.S., Szlachcic Y., Gong Jr. H., Patrick L., Kinney P.L. and Berhane K.T., Air pollution and daily hospital admissions in Metropolitan Los Angeles, *Environmental Health Perspectives*, 108 (5), 427-435 (2000)
 - ♦ McCune DC, Hitchcock AE, Jacobson JS. 1965. Fluoride accumulation and growth of plants exposed to particulate cryolite in the atmosphere. Contributions from Boyce Thompson Institute, 23: 1-22
 - ♦ Meo S.A., Azeem M.A., Ghori M.G. and Subhan M.M., Lung function and surface electromyography of intercostal muscles in cement mill workers, *Int J Occup Med Environ Health*, 15(3), 279-287 (2002)
 - ♦ Namdeo, A. and Bell, M.C. 2005. Characteristics and health implications of fine and coarse particulates at roadside, urban background and rural sites in UK. *Environ. Int.*, (31): 565-573.
 - ♦ Park, J.E. and Park, K. 1985. Preventive and social medicine. Banarsidas Bhanot (Publishers), Napier town, Jabalpur, India.
 - ♦ Parthasarathy S, Arunachalam M, Natarajan K. 1975. Effect of cement dust pollution on certain physical parameter of maize crop and soils. *Indian Journal of Environmental Health*, 17: 114-120
 - ♦ Perez, P. and Reyes, J. 2002. Prediction of maximum of 24-h average of PM10 concentrations 30-h in advance in Santiago, Chile. *Atmos. Environ.*, (36): 4555-4561.
 - ♦ Prajapati SK. 2012. Ecological effect of airborne particulate matter on plants. *Environmental Skeptics and Critics*, 1(1): 12-22
 - ♦ Pregger T, Friedrich R. 2009. Effective pollution emission heights for atmospheric transport modeling based on real-world information. *Environmental Pollution*, 157: 552-560
 - ♦ Saez M., Ballester F., Barcelo M.A., et al., A combined analysis of the short-term effect of phytochemical air pollutants on Mortality within the EMECAM project, *Environmental Health Perspectives*, 110 (3), 221-228 (2002)
 - ♦ Salam, A., Bauer, H., Kassin, K., Ullah, S.M. and Puxbaum, H. 2003. Aerosol chemical characteristics of a mega-city in southeast Asia (Dhaka, Bangladesh). *Atmos. Environ.*, (3): 2517-2528.
 - ♦ Lin, J. and Lee, L.C. 2004. Characterization of the concentration and distribution of urban submicron PM10 aerosol particles. *Atmos. Environ.*, (38): 469-475.
 - ♦ Shrivastava J. 1999. Studies on the air quality status and its impacts on vegetation proximate or cement plant of Sarlanager, Maihar (M.P.). PhD Thesis, University Rewa (M.P.), India
 - ♦ Singh SN, Rao DN. 1978. Effect of cement dust pollution on soil properties and on wheat plants. *Indian Journal of Environmental Health*, 20: 258-267
 - ♦ Tiwari MK, Mishra RM, Dwivedi S. 2011. Deterioration of air quality and human health in Naubasta village due to air pollution by J.P. Cement plant Rewa (M.P.). *International Journal of Pharmacy and Life*
-

Arsenic: Occurrence and Health Hazard

Bhupendra Kumar Mishra*

ABSTRACT

Arsenic is a carcinogen heavy metal to both humans and animals. It is a slow poison, has contaminated the environment from both anthropogenic and natural sources whole over the world and its exposure has caused adverse health effects on human beings, thus becoming a global concern. Arsenic is widely distributed and observed in the natural environments such as in water, sediment, soil and rock. Thus ingestion of edible foods, drinking water and its usages are the main pathways for arsenic borne diseases to human beings.

Keyword: Arsenic, Occurrence, Health hazard

INTRODUCTION

Arsenic is associated with many problems, being a natural and anthropogenic contaminant in areas where human subsistence is at risk. It comprises a large number of chemical species with widely differing toxicities, and producing non-specific pathologies which are hard to diagnose. Anthropogenic point sources also contribute to Arsenic found in the environment. These include smelter slag, coal combustion, run off from mine tailings, hide tanning waste, pigment production for paints and dyes, and the processing of pressure-treated wood (e.g., copper chromate arsenate). Arsenic contamination of drinking water has been found to be a frequent cause of skin cancer and gastro-intestinal problems. Every year, new areas are detected in which the presence of Arsenic exceeds the WHO limit (10µg/L or 10ppb) for safe drinking water. All these reasons indicate the need to carry out cross-border and interdisciplinary studies.

The situation of Arsenic toxicity in India is alarming with reports of severe health problems among the populations of various states including West Bengal (WB), Bihar, Assam, Chhattisgarh, Delhi, Uttar Pradesh, NE regions as shown in figure 1.1 (Saha and Chakrabarti, 1995; Bhattacharya et al., 1997; Pandey et al., 1999; Chowdhury et al., 2000; Acharyya et al., 2005; Chakraborti et al., 2008; Shukla et al., 2010; Dubey et al., 2010; 2012). Approximately 41-57 million people are potentially exposed to elevated levels of Arsenic, from 10 to 10,000 µg/L, especially in the Bengal Basin Area (Bangladesh and West Bengal, India) (Smedley, 2005; Rahman et al., 2009).

* Department of Mining Engineering, AKS University, Satna, M. P.
Corresponding Author: bhupendrageo@gmail.com

There are three major sources (hotspots) of Arsenic contamination in India. The Arsenic contamination in Ganga Brahmaputra Delta Plain is from Ophiolites of Himalayas (natural source) which contaminated Trans and Tibetan Himalayas also (Guillot and Charlet, 2007). The Arsenic contamination of the groundwater and the consequent human affliction observed in West Bengal, Rajnandgaon district of Chhattisgarh state and Kakching area of Manipur has geogenic (natural) sources (Acharyya et al., 2005; Shukla et al., 2010; Usham et al., 2012, 2018). The Arsenic contamination in Delhi, where >100 ppb of Arsenic concentration is observed in groundwater, has anthropogenic source mainly coal figure 1.2 (Dubey et al., 2010; 2012).

OCCURANCE

Various hypotheses describe the mechanisms of Arsenic release in ground water. For example, (Charlet and Polya, 2006) suggested oxidation of Arsenic rich pyrite, phosphate adsorption from agricultural fields for Arsenic desorption, and microbiologically mediated reductive dissolution for Arsenic release and mobilization. Nevertheless, none of the hypotheses can fully explain or unanimously agree on the governing mechanism in the real world (Acharyya, 2002). Acharyya et al., (2005) supported pyrite oxidation theory as the main mechanism, but suggested that this theory plays a minor role in Arsenic release in West Bengal area as no such deposit of arsenopyrite is found. Pandey et al., (2002) proposed an "oxidation-reduction theory" in which Arsenic originates first from arsenopyrite oxidation and then mobilized Arsenic reduces underground in favorable Eh conditions. A combination of these theories could possibly explain

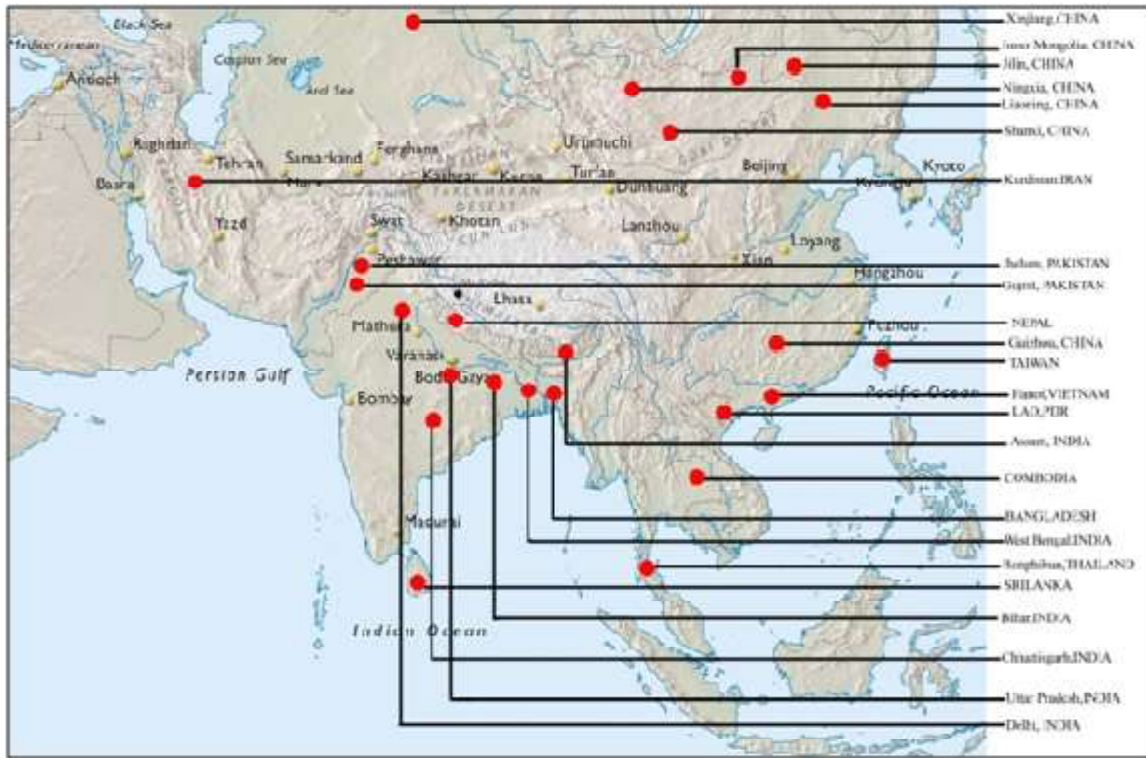


Figure: 1.1: Arsenic Contamination Locations in the Asia (Source: Samal, 2005; Dubey et al. 2010; Shukla, 2012).

the mechanism of Arsenic release and mobilization (Shukla et al., 2010).

Arsenic contaminated drinking water is one of the most challenging environmental problems today. Currently millions of people suffer due to Arsenic problem in the world. The most prominent Arsenic contaminated areas are located in parts of Taiwan, China, South America, Southeast Asia Argentina, Bangladesh, Chile, China, Hungary, Mexico, Romania, Taiwan, Vietnam and parts of the USA, and SE Asia (Figure 1.1). (Smedley and Kinniburgh, 2002; Samal, 2005; Bromssen et al., 2007; Sampson et al., 2008; Rahman et al., 2009; Dubey et al. 2012; Shukla, 2012).

The high concentration of >1000 ppb of Arsenic in ground waters of Bangladesh and West Bengal, causing various diseases, is majorly contributed to Arsenic in the soil and peat layers of alluvium. Though the Arsenic concentration of >250 ppb in ground waters of Chattisgarh in Central India is attributed to rock and mineral chemistry of the area and has nothing to do with riverine deposits, while people still suffer from similar diseases (Shukla et al.,

2010). However, there have been reports of anthropogenic contamination in Delhi where >100 ppb of Arsenic concentration is observed in groundwater. The coal used in Thermal Power Plants in Delhi is reported as the Arsenic bearing rock and is being used without proper treatment (Mishra, 2014; Dubey et al., 2012, 2021).

Majumder et al., (2013) suggested that cultivation of jute after summer rice in West Bengal may be a good option to stabilize soil Arsenic content. However, its retting pollutes surface water bodies, which will act as a new source of Arsenic toxicity in aquatic eco-system. Neidhardt et al., (2013) reported temporal changes of Arsenic concentrations in shallow groundwater of the Bengal Delta Plain (BDP). They observed that the fluctuations are primarily induced by seasonally occurring groundwater movement, but hinted that it can also be connected to anthropogenic groundwater extraction. Bhowmick et al., (2012) concluded that the Arsenic release in West Bengal is influenced by both geogenic (i.e. geomorphology) and anthropogenic (i.e. unsewered sanitation) processes. They found that the release of Arsenic in ground waters of Debagram and Baruipur were due to a complex

ARSENIC: OCCURRENCE AND HEALTH HAZARD

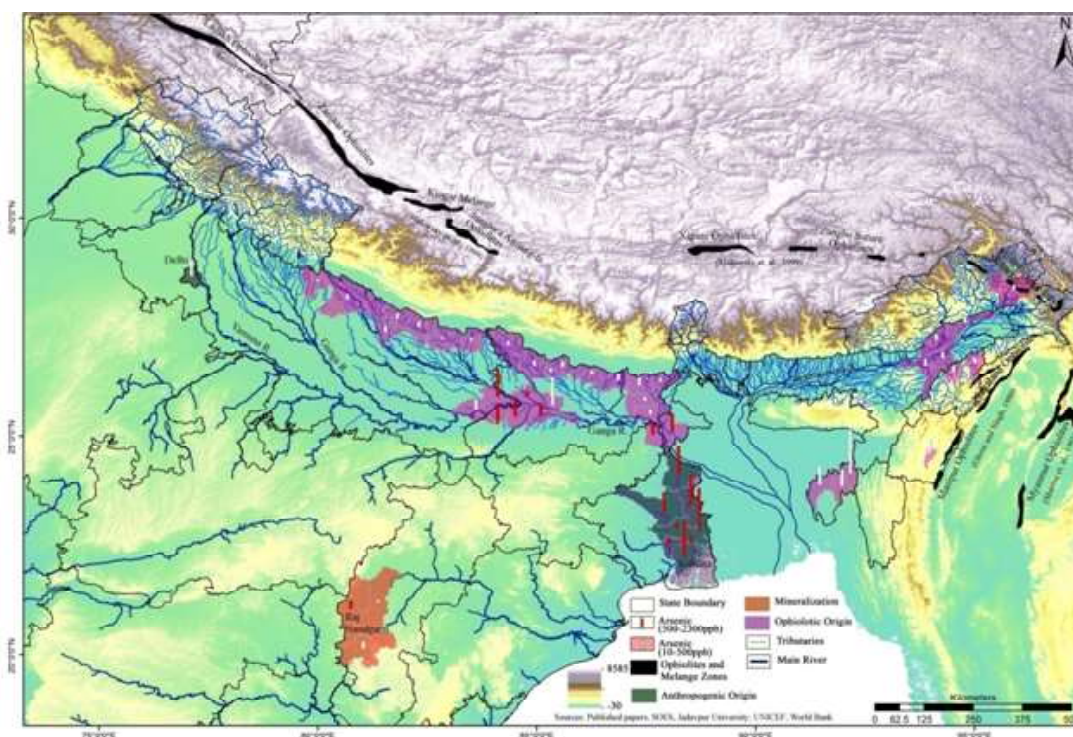


Figure 1.2: 3-Hotspots of Arsenic contamination in India showing various levels of concentration in groundwater. Red and White vertical bars show concentration more than and less than 500 ppb or µg/L respectively (Modified after WBTR, 2004; Dubey et al., 2010; Shukla, 2012).

combination of processes such as carbonate mineral dissolution and reduction of Fe-oxyhydroxides. Neal et al., (2010) studied the contrasting Arsenic concentrations west (low-Arsenic) and east (high-Arsenic) of the river Bhagirathi and observed mineralogical differences between (grey) sediments bearing high-Arsenic ground waters and (orange-brown) sediments bearing low-Arsenic ground waters. They observed greater amounts of micas, Fe- and Mg-rich clays, amphiboles, carbonates, and apatite in high-Arsenic sediments; which were virtually absent from low-Arsenic sediments.

HEALTH HAZARD

Arsenical toxicity develops insidiously after six months to two years or more depending on the amount of intake of arsenic laden ground water and arsenic concentration in the water. As per clinical report finding the arsenic poisoning from arsenic contaminated drinking water show the approx all stages of stages of clinical expression (Hotta, 1989). After the intake of arsenic into the human body, approximately 50% of the arsenic is excreted in the

urine (Das, 1995; Das et al., 1995) with small portions through the faces, skin, hair, nails and lungs. People drinking arsenic contaminated water generally show arsenical skin diseases. People use long term arsenic contaminated drinking water may suffer to various diseases such as conjunctivitis, hyperkeratosis, hyperpigmentation, cardiovascular diseases, disturbance in the peripheral vascular and nervous systems, skin cancer, gangrene, leucomelosis, nonpitting swelling, hematological, splenomegaly, hepatic, renal, dermal, genotoxicity, mutagenic etc.

CONCLUSION

Arsenic, the king of poisons, has probably influenced human history more than any other element or toxic compound. For the thousands of years that people have worked and lived with this enigmatic element, tens of thousands have died of it and millions have been sickened by it. Today, As still remains a part of our daily lives and millions of people are being chronically exposed to

elevated doses of As from their food, air, water, and soils with unknown long term health consequences.

In Delhi revealed shocking outcomes with arsenic concentrations well beyond the safe limits set by WHO, and a maximum concentration up to 180 ppb was found in the groundwater. Analysis of around 120 water samples collected extensively along the Yamuna Flood Plain showed that more than 55% had arsenic contamination beyond the WHO limit of 10 ppb. The maximum value of arsenic in coal and fly ash from Rajghat coal-based thermal power plant contained 200 and 3,200 ppb, respectively. Moreover, the ore petrography of coal samples shows the presence of arsenopyrite mineral. Maximum concentration of arsenic contamination is found within a 5-km radius from power plants.

The affected areas of West Bengal are low-lying, topographically flat, flood prone alluvial flood plains of rivers that originate from the Himalayas. This region is densely populated and currently has nearly 11 thermal power plants (TPPs) consuming bituminous coal. The combustion of coal generates huge amounts of ash, which is disposed-off in large fly ash ponds (FAP) and landfills and only a small fraction of it is utilized. More than 150 samples of coal, fly ash, soil, slurry, drain water and surface water were collected from West Bengal. Random grab sampling was carried out as the area is vast so grid sampling was not feasible. The samples from nearly all the fly ash ponds of 11 TPPs, their drain water and slurry water samples and surface water, mainly river and canal which are used as a feeder to TPPs, were collected. Coal samples were collected from the Raniganj, Durgapur coal fields as well as the coal being utilized in these TPP's.

Analysis of water, coal, fly ash and soil of the all TPPs samples revealed the high concentration of Arsenic and other heavy metals minerals. Nearly all the water samples had Arsenic concentration well above the WHO limit of 10 µg/L. The chemical analysis for soil, fly ash and coal samples also showed high concentration of Arsenic as well as high concentrations of Iron, Manganese, Chromium, Lead and Copper. The concentration of various elements such as Arsenic (As), Fluoride (F), Iron (Fe), Chromium (Cr), Copper (Cu), Manganese (Mn), Mercury (Hg), Cadmium (Cd), Lead (Pb), Zinc (Zn) were compared as per WHO and CPCB limits. It is observable to summaries that geographical distribution of arsenic, quantification of different types of species, their

solubility and bioavailability, and considerable geochemical processes responsible for prominent arsenic concentration in the environment is very much needed for effective the management of water resources and human being. Presently there are few countries where arsenic contamination in the groundwater has reached a very alarming level and requires instant attention, especially in Bangladesh and India. Arsenic contaminated coal widespread areas, possible intervention options are to use coals with arsenic concentration that does not pose any health risk and to improve the indoor air ventilation systems.

REFERENCES

- ♦ Acharyya SK (2002) Arsenic contamination in groundwater affecting major parts of southern West Bengal and parts of western Chhattisgarh: source and mobilization processes. *Current Science*, 82:740–744.
- ♦ Acharyya SK, Shah BA, Ashyia ID and Pandey Y (2005) Arsenic contamination in groundwater from parts of Ambagarh-Chowki block, Chhattisgarh, India: Source and release mechanism. *Environmental Geology*, 49:148–158.
- ♦ Bhattacharya P, Chatterjee D and Jaks G (1997) Occurrence of As-contaminated groundwater in alluvial aquifers from Delta Plains, Eastern India: options for safe drinking water. *Water Resource Development*, 13:79–92.
- ♦ Bhowmick S, Nath B, Halder D, Biswas A, Majumder S, Mondal P, Chakraborty S, Nriagu J, Bhattacharya P, Iglesias M, Roman-Ross G, Mazumder DG, Bundschuh J and Chatterjee D (2012) Arsenic mobilization in the aquifers of three physiographic settings of West Bengal, India: Understanding geogenic and anthropogenic influences. *Journal of Hazardous Materials*, <http://dx.doi.org/10.1016/j.jhazmat.2012.07.014>.
- ♦ Bromssen MV, Jakariya M, Bhattacharya P, Ahmed KM, Hasan MA, Sracek O, Jonsson L, Lundell L and Jaks G (2007) Targeting low-Arsenic aquifers in Matlab Upazila, Southeastern Bangladesh. *Science of the Total Environment*, 379 (2–3):121–132. (ISSN 0048-9697, DOI: 10.1016/j.scitotenv.2006.06.028).

ARSENIC: OCCURRENCE AND HEALTH HAZARD

- ♦ Chakraborti D, Singh EJ, Das B, Shah BA, Hossain MA, Nayak B, Ahamed S and Singh NR (2008) Groundwater Arsenic contamination in Manipur, one of the seven North-Eastern Hill states of India: a future danger. *Environmental Geology*,56:381–390.
- ♦ Charlet L and Polya DA (2006) Arsenic in shallow reducing groundwaters in southern Asia: an environmental health disaster. *Elements*, 2:91–96.
- ♦ Chowdhury UK, Biswas BK, Chowdhury TR, Samanta G, Mandal BK, Basu GK, Chanda CR, Lodh D, Saha KC, Mukherjee SK, Roy S, Kabir S, Quamruzzaman Q and Chakraborti D (2000) Ground water Arsenic contamination in Bangladesh and West Bengal-India. *Environ Health Perspect*,108:393–397.
- ♦ Dubey CS, Mishra BK, Shukla DP, Singh RP, Tajbakhsh M and Sakhare P (2012) Anthropogenic Arsenic menace in Delhi Yamuna Flood Plains. *Environmental Earth Sciences*,65:131–139.
- ♦ Dubey, C.S., Shukla, D.P. and Mishra, B.K. (2010). Arsenic Contamination in India: 3 Hotspots. *Hydrology Conference 2010*, HYDR2010-0289, 11th – 13th October, 2010, San Diego, CA, USA.
- ♦ Dubey C. S., Usham A. L., Mishra B. K., Shukla D. P., Singh P. K., Singh A. K. (2021) Anthropogenic arsenic menace in contaminated water near thermal power plants and coal mining area of India. *Environmental Geochemistry Health*. <https://doi.org/10.1007/s10653-021-01010-0>
- ♦ Das D., Chatterjee A., Mandal B. K., Samanta G., Chakraborty D. and Chanda B. (1995) Arsenic in groundwater in six districts of West Bengal, India: the biggest arsenic calamity in the world. Part 2. Arsenic concentration in drinking water, hair, nails, urine, skin-scales and liver tissues (biopsy) of the affected people. *Analyst* 120, 917-924.
- ♦ Guillot S and Charlet L (2007) Bengal Arsenic, an archive of Himalaya orogeny and Paleohydrology. *Journal of Environmental Science and Health Part A*, 42(12):1785-1794.
- ♦ Hotta N. (1989) Clinical aspects of chronic arsenic poisoning due to environmental and occupational pollution in and around a small refining spot. *Jpn. J. Const. Med.* 53, 49-59.
- ♦ Jain C. K. and Ali A. (2000) Arsenic: occurrence, toxicity and speciation techniques, *Wat. Res.* Vol. 34, No. 17, pp. 4304-4312.
- ♦ Majumder A, Bairagya MD, Basu B, Gupta PC, Sarkar S (2013) Retting of jute grown in Arsenic contaminated area and consequent Arsenic pollution in surface water bodies. *Science of the Total Environment*, 442:247–254.
- ♦ Mishra B. K., Dubey C. S. , Shukla D P., Bhattacharya P., Usham A L (2014) Concentration of arsenic by selected vegetables cultivated in the Yamuna Flood Plains (YFP) of Delhi, India. *Environmental Earth Sciences*: 72 Pp.3281-3291
- ♦ Neal AW (2010) Hydrogeochemical and Mineralogical evaluation of groundwater Arsenic Contamination in Murshidabad District, West Bengal, India. M.Sc. Thesis, Department of Geology, College of Arts and Sciences, Kansas State University, Manhattan, Kansas.
- ♦ Neidhardt H, Berner Z, Freikowsk D, Biswas A, Winter J, Chatterjee D, Norra S (2013) Influences of groundwater extraction on the distribution of dissolved As in shallow aquifers of West Bengal, India. *Journal of Hazardous Materials*,<http://dx.doi.org/10.1016/j.jhazmat.2013.01.044>.
- ♦ Pandey PK, Patel KS and Subrt P (1999) Trace element composition of atmospheric particulate at Bhilai in central – east India. *Science Total Environment*, 215:123-134.
- ♦ Pandey PK, Yadav S, Nair S and Bhui A (2002) Arsenic contamination of the environment: a new perspective from central-east India. *Environment International*, 28:235–345.
- ♦ Rahman M, Naidu R and Bhattacharya P (2009) Arsenic contamination in groundwater in the Southeast Asia region. *Environmental Geochemistry and Health*, 31:9–21. (<http://dx.doi.org/10.1007/s10653-008-9233-2>)

- ♦ Saha GC and Chakrabarti C (1995) Geological and geochemical background of the Arsenic bearing groundwater occurrence of West Bengal. *Proceedings of the International Conference on Arsenic in Groundwater: Cause Effect and Remedy, Kolkata.*
 - ♦ Samal AC (2005) An investigation on the accumulation of Arsenic in ecosystem of Gangetic West Bengal and assessment of potential health risk. Ph. D. Thesis, Department of Environmental Science, University of Kalyani, Nadia, West Bengal.
 - ♦ Sampson ML, Bostick B, Chiew H, Hagan JM and Shantz A (2008) Arsenicosis in Cambodia: Case studies and policy response. *Applied Geochemistry*, 23 (11):2977-2986. (Arsenic in groundwaters of South-East Asia: With emphasis on Cambodia and Vietnam, November 2008. (ISSN 0883-2927, DOI: 10.1016/j.apgeochem.2008.06.022).
 - ♦ Shukla DP (2012) Multi-Disciplinary Approach Using Hydro-Geochemical Analysis, Remote Sensing-GIS Technique and Mitigation for Arsenic Contaminated Groundwater in Rajnandgaon, Central India. Unpublished Ph.D. Thesis, Department of Geology, University of Delhi, Delhi.
 - ♦ Shukla DP, Dubey CS, Singh NP, Tajbakhsh M and Chaudhry M (2010) Sources and controls of Arsenic contamination in Rajnandgaon and Kanker District, Chhattisgarh, Central India. *Journal of Hydrology*, 395:49–66.
 - ♦ Smedley PL (2005) Arsenic occurrence in groundwater in South and East Asia—scale, causes and mitigation. *In: Towards a More Effective Operational Response: Arsenic Contamination of Groundwater in South and East Asian Countries*, Volume II Technical Report, World Bank Report No. 31303.
 - ♦ Smedley PL and Kinniburgh DG (2002) A review of the source, behaviour, and distribution of Arsenic in natural waters: a review. *Applied Geochemistry*, 17:517 – 568.
 - ♦ Usham AL, Dubey CS, Singh NP, Mishra BK, Shukla DP, Singh RP, Naorem SS and Thoithoi (2012) Source of Arsenic Contamination in Kakching Area, Manipur. *Annual International Conference on Geological and Earth Sciences*, Singapore.
 - ♦ Usham A. L., Dubey C. S., Shukla D. P., Mishra B. K., Bhartiya G.P. (2018) Sources of Fluoride Contamination in Singrauli with Special Reference to Rihand Reservoir and its Surrounding. *Journal Geological Society of India*. Vol.91, pp.441-448.
 - ♦ WBTR (The World Bank Technical Report) (2004) Towards a more effective operational response: Arsenic Contamination of Ground Water in South and East Asian Countries, **Volume II Technical Report No. 31303.**
-

Profile Particulate Matter Generated at Higher Depths in Opencast Mines

Sneha Gautam* Basanta Kumar Prusty* Aditya Kumar Patra*

ABSTRACT

Dispersion studies of particulate matter generated during opencast mining until now have mostly been confined to estimation of emissions from individual mining activity as well as total emission from an opencast mine. No study is available on particulate matter dispersion inside the mine since its generation until it escapes the mine. However, this is important, particularly for deep mines where mine workings are confined to bottom benches and emission from it passes across all benches before it reaches the surface, thus affecting the exposure level of workers at higher benches. This paper presents the results of a study on the dispersion of particulate matter in Malanjkhand Copper Project, one of the deepest opencast mines in India. The study was conducted for 4 – 5 hours daily for 10 days during the month of October 2013. Coarse particle ($PM_{2.5-10}$) constituted 6 to 8% of the background concentration. During mining, it increased to 31 to 61%, due to generation of coarser particles during mining. From source locations to the surface, the average mining induced incremental concentration of $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 decreased from 127.02 to 3.98 $\mu g m^{-3}$, 5.39 to 1.95 $\mu g m^{-3}$ and 20.26 to 2.74 $\mu g m^{-3}$ respectively. An empirical relationship has been established between particulate matter concentration and depth.

Keywords

Opencast mine; Dispersion; Particulate matter; Relative concentration; Relative depth; Predictor equation

INTRODUCTION

As impacts of particulate matter from mining on human health got widely reported, studies on generation and dispersion of particulate matter during mining were carried out. While some studies focussed on estimation of particulate matter generated by a mining activity (Chaulya, 2004; Ghose, 2007; Zhang et al., 2013), several other studies measured the contribution of a surface mine to the particulate matter level in atmosphere near the mine (Chakraborty et al., 2002; Trivedi et al., 2009). Most of the studies reported that mining operations generate more inhalable coarse particulate matter ($PM_{2.5-10}$) than fines ($PM_{2.5}$) (Aneja et al., 2012; Onder and Yigit, 2009; Tecer et al., 2008). Empirical formulae have been developed to estimate the emissions from different mining operations (Chakraborty et al., 2002; Chaulya et al., 2002; Ghose and Majee, 2001). A few studies were aimed to estimate the change of concentration of particulate matter with increasing distance from the mine boundary (Trivedi et al., 2009, 2011).

While quantification of particulate matter generated from mining activities is important, understanding its dispersion inside the mine is equally important because the nature of dispersion will determine the level and duration to which a miner is exposed to mining induced particulate matter. Particulate matter generated at the lower benches of a mine travels across all the higher benches before it escapes the mine. Therefore an activity at deeper parts of the mine contributes to the enhanced concentration at higher benches. Time taken by the particulate matter generated at a certain depth to escape the mine is therefore important. If the time taken for the particulate matter to escape the mine is very long, it indicates that workers inside the mine are exposed to elevated concentration for a longer duration. On the other hand, if the particulate matter escapes the mine in a short time, its adverse effect on health will be less due to less exposure duration. Further, as the particulate matter travel from lower part of the mine to upper horizons, not all particles travel at same speed and proportion. A coarser particle with higher settling velocity settles on mine floor faster than fine particles and therefore may get depleted from the particulate matter plume as it travels higher. No

*Department of Mining Engineering,
Indian Institute of Technology Kharagpur, Kharagpur-721302, India
Corresponding Author: akpatra@mining.iitkgp.ernet.in

study has been conducted to estimate this dispersion pattern of particulate matter inside the mine as they travel from source to the mine boundary. With opencast mines going deeper day by day, the study of dust dispersion inside the mine needs attention.

The paper presents the outcome of a dust dispersion study in Malanjkhand copper project in India. The main objectives of the study included estimation of contribution of mining to the particulate matter level inside the mine and understanding particulate matter dispersion as they travel from source to the surface.

EXPERIMENTAL METHODOLOGY

Study site

The study was conducted in Malanjkhand Copper Project (MCP) of Hindustan Copper Limited (HCL). MCP is the single largest copper deposit in India constituting nearly 80% of country's reserve. The ultimate pit design provides for deepening the pit up to 376 mRL i.e. around 200 m from surface. The pit has already been deepened up to 400 mRL. The average height of each bench is 12 m. The pit size of MCP is 2200 m x 600m. The entire pit at MCP is divided into three sections, namely, North, Central and South pit. The present study was carried out in Central pit (Fig. 1).

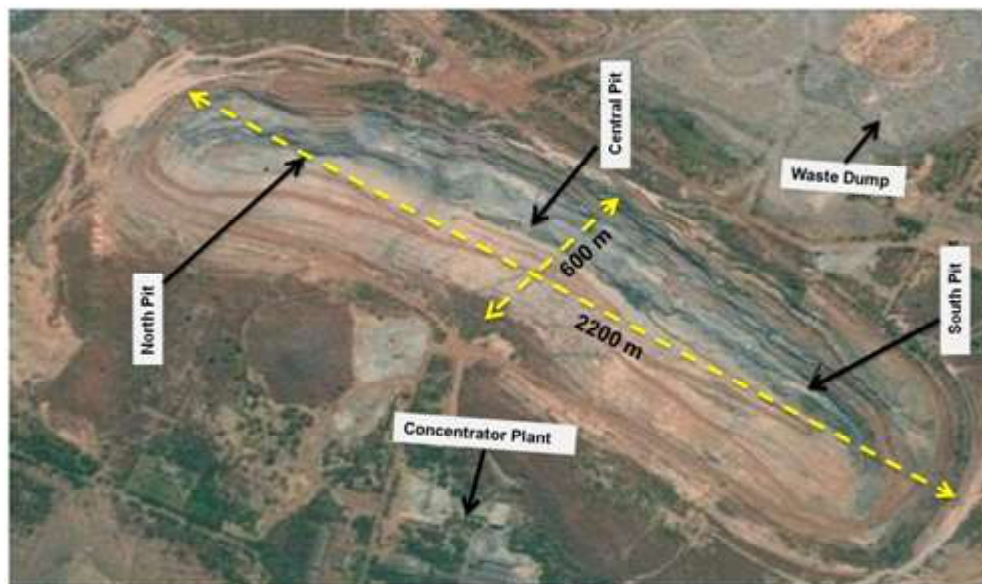


Fig. 1: Layout of Malanjkhand Copper Project

Instruments for data collection

Particulate matter concentration was measured using an aerosol spectrometer (Model 1.108, Grimm, GRIMM Aerosol Technik GmbH & Co. KG, Germany). Grimm aerosol spectrometer is a portable instrument which provides continuous measurement of aerosols in mass and number concentration. By counting the scattering light pulse of each particle, the optical counter classifies the sampled particles into 15 size ranges (0.3 to 20 μm), depending on the intensity of the scattered light. A portable weather station (Spectrum Technologies, Inc., Model Watchdog 2000) was used to measure local meteorology. The weather station records wind direction, wind speed, humidity, pressure, temperature, dew point, solar

radiation, and rainfall. It has built-in data logger that stores data (Spectrum, 2010).

Sampling location and duration

Sampling was carried out on benches having 400, 412, 448, and 460 mRL and also at the pit boundary on surface at 580 mRL. At central pit, drilling of blast holes by drill machines, loading of blasted ore by shovel and transport of ore to the concentrator plant by dumpers at 400 and 412 mRL constituted the source of particulate matter emission. Therefore particulate matter concentration at these two benches gives the estimate of particulate matter generated due to mining activities. 580 mRL refers to the surface and therefore measurement at this location shows

PROFILE PARTICULATE MATTER GENERATED AT HIGHER DEPTHS IN OPENCAST MINES

the particulate matter level at the pit boundary. Between 412 and 580 mRL, 13 benches of 12 m height are present. Measurements were taken at two out of these 13 benches (448 and 460 mRL) which were accessible at the time of

the study. One Grimm aerosol spectrometer and a weather station at each location recorded particulate matter concentration and local meteorology respectively (Fig. 2).

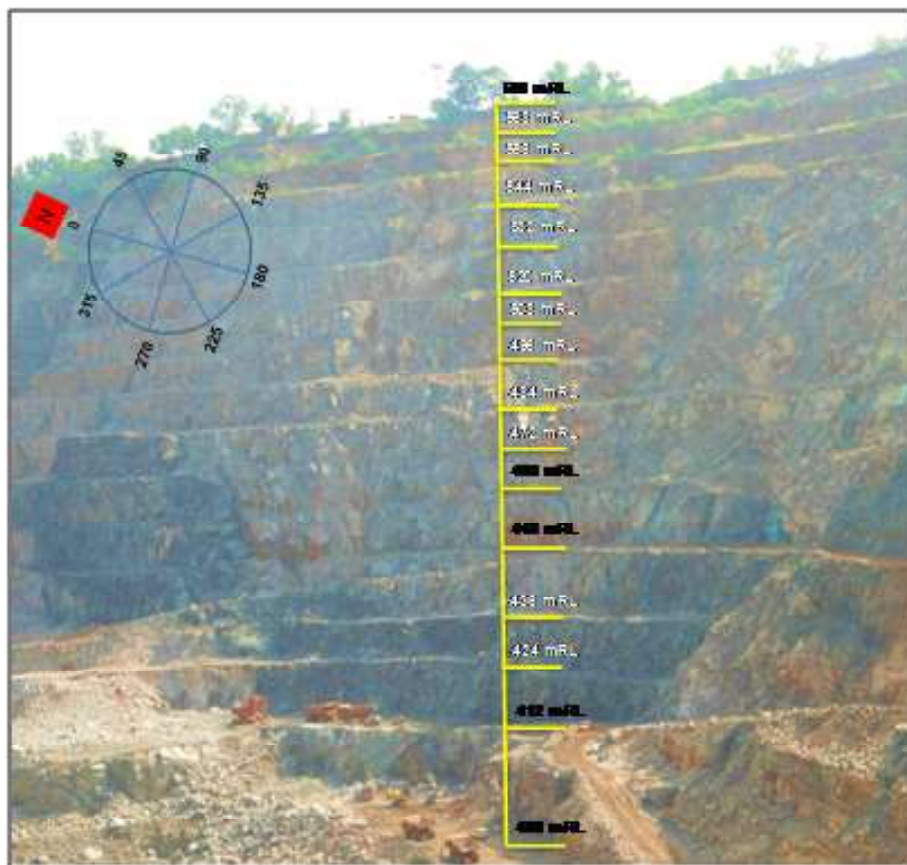


Fig. 2: Sections of the mine at sampling locations (RLs written in black indicates the locations of sampling)

The study was carried out during the first shift during 12 - 24 October 2013. The duration of first shift is from 6:00 to 14:00. However, on each day, the working of the shift ends at 13:00 in order to evacuate the mine for daily blasting scheduled at 14:00. Further, during the shift, work remains suspended from 8:30 to 9:00 for tea break. Therefore first shift work consists of two working phases, i.e. a short duration first phase from 6:00 to 8:30 and a longer second phase from 9:00 to 13:00. On all days sampling started after end of the first phase and before start of the second phase of mining. On one day sampling started before the end of first phase of mining. At each of the five locations (400, 412, 448, 460 and 580 mRL), sampling was carried out on two consecutive days.

RESULTS AND DISCUSSION

Wind speed and wind direction

In the mine, the highest wind speed of 4.44 m s^{-1} was recorded at two bottom most benches (400 and 412 mRL). Maximum and average wind speed on surface was the highest among all locations on both the days. At all the locations on several occasions the wind speed was zero. On second day of study at 448 mRL, 75% of the time wind speed was zero. Mean wind speeds of 0.29 m s^{-1} and 0.16 m s^{-1} at 448 mRL on day 1 and 2 respectively, were the lowest among mean wind speeds at all locations. Mean wind speed and maximum wind speed at surface (580 mRL) were the highest among all measurements (Table 1). The mean wind speeds at 448 and 460 mRL

were 10-40% of the wind speeds at bottom two benches and on surface. Wind speed did not follow a regular trend with depth. Irregular pattern of wind speed with depth in

surface mines has also been observed in earlier studies (Chowdhury, 1977).

Table 1 : Descriptive statistics of wind speed (m s⁻¹)

Depth (mRL)	No of observations (n)	Mean	SD	25%	50%	75%	Minimum	Maximum
400	Day 1 (n = 248)	1.12	1.01	0.27	0.83	1.66	0	4.44
	Day 2 (n = 158)	1.05	0.77	0.27	1.11	1.66	0	3.33
412	Day 1 (n =256)	1.47	0.98	0.83	1.11	2.22	0	4.44
	Day 2 (n =263)	1.83	1.20	0.83	1.66	2.5	0	4.72
448	Day 1 (n = 198)	0.29	0.49	0	0	0.27	0	2.22
	Day 2 (n = 228)	0.16	0.39	0	0	0	0	2.22
460	Day 1 (n = 226)	0.35	0.57	0	0	0.83	0	3.05
	Day 2 (n = 226)	0.51	0.66	0	0.27	0.83	0	3.33
580	Day 1 (n = 245)	1.84	0.96	1.11	1.66	2.5	0	4.44
	Day 2 (n = 240)	2.1	0.97	1.66	2.22	3.05	0	4.72

Wind direction varied on different benches as well as between two days of sampling at one bench. Mean wind direction was NE for 5 days, SE for 3 days and NW for 2 days. On 3 days, wind direction varied widely across all directions. However, on remaining 7 days wind direction variation was limited to 180°.

The lowest concentration recorded on any day is attributed as the local background concentration of the mine for that day. On both days at all five locations fine particles (PM₁) dominated the background concentration because fine particles remain airborne for a longer time than coarse particles. Average background concentrations of PM_{2.5-10}, PM_{1-2.5} and PM₁ varied from 0.4 to 2.1 µg m⁻³, 0.8 to 2.05 µg m⁻³ and 4.1 to 21.5 µg m⁻³ respectively (Fig. 3).

Particulate matter profile
Background concentration

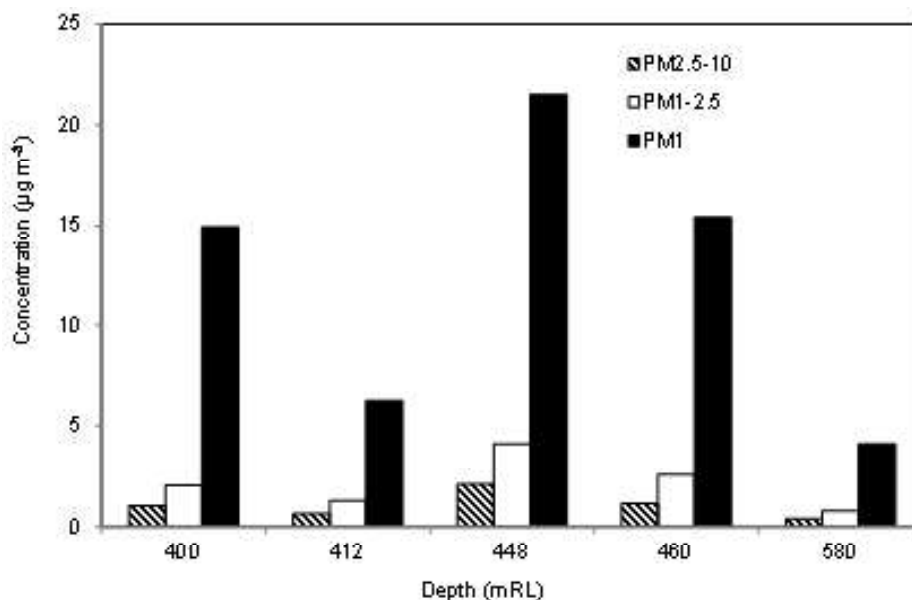


Fig. 3: Background concentration of particulate matter

PROFILE PARTICULATE MATTER GENERATED AT HIGHER DEPTHS IN OPENCAST MINES

The average proportion of $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 varied from 6 to 8 %, 11 to 16 % and 77 to 83%, respectively (Fig. 4).

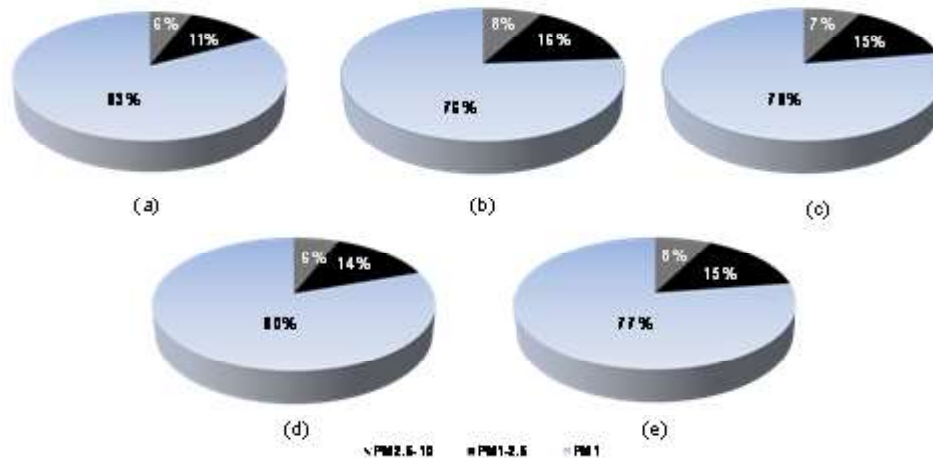


Fig.4: Proportion of $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 in background concentration; (a) 400 mRL, (b) 412 mRL, (c) 448 mRL, (d) 460 mRL and (e) 580 mRL

Fig. 5 shows the time series of concentration of particulate matter before and during mining. Drilling of blast holes was carried out during first phase of working which, on some days, was extended to within the tea break period. Drilling produces the highest amount of particulate matter emission among all mining activities (Onder and Yigit, 2009). Therefore, the concentration of particulate matter of all sizes was higher than background concentrations at all sampling locations before the start of the second phase of mining (Fig. 5).

Near the source coarse particle concentration ($PM_{2.5-10}$ and $PM_{1-2.5}$) was higher than fines (PM_1) (Figs. 5a & 5b). Proportionately higher amount fine particles move up due to its low settling velocity. This resulted in PM_1 concentration being higher than the concentration of $PM_{2.5-10}$ and $PM_{1-2.5}$ at 448 and 460 mRL (Figs. 5c & 5d). No drilling was carried out during second phase of mining. Therefore, the generation of particulate matter of all sizes was less in comparison to that generated during drilling. Moreover, out of all sizes, generation of PM_1 was the lowest. Thus PM_1 concentration did not exceed that was prevailing before the start of second phase and it decreased continuously throughout the second phase of mining (Figs. 5c & 5d). During second day of sampling at 580 mRL, a drill was in operation at 412mRL, in addition to other mining machineries. This additional source resulted in enhanced PM_1 concentration on second day of sampling at 580 mRL (Fig. 5e).

Irrespective of depth and location of source, the contribution of mining was the highest for $PM_{2.5-10}$ at all sampling locations (Fig. 6). This suggests that when working is in progress inside an opencast mine, particulate matter generated at deeper parts of the mine travels to all higher benches and makes presence of coarse particles prevalent at all heights.

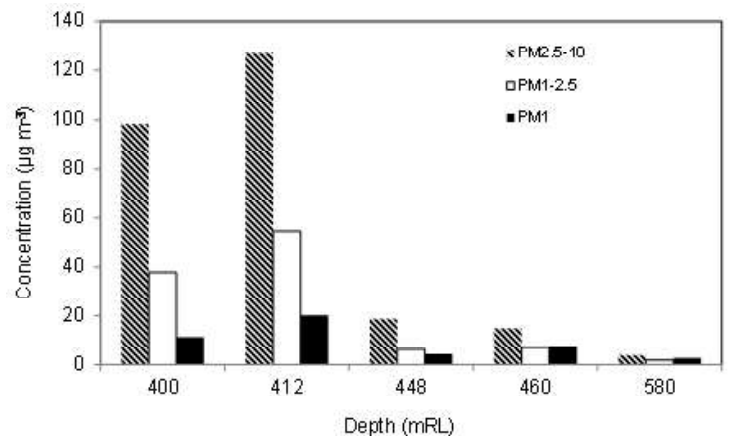


Fig. 6: Incremental concentrations of particulate matter due to mining

Particulate matter emission due to mining

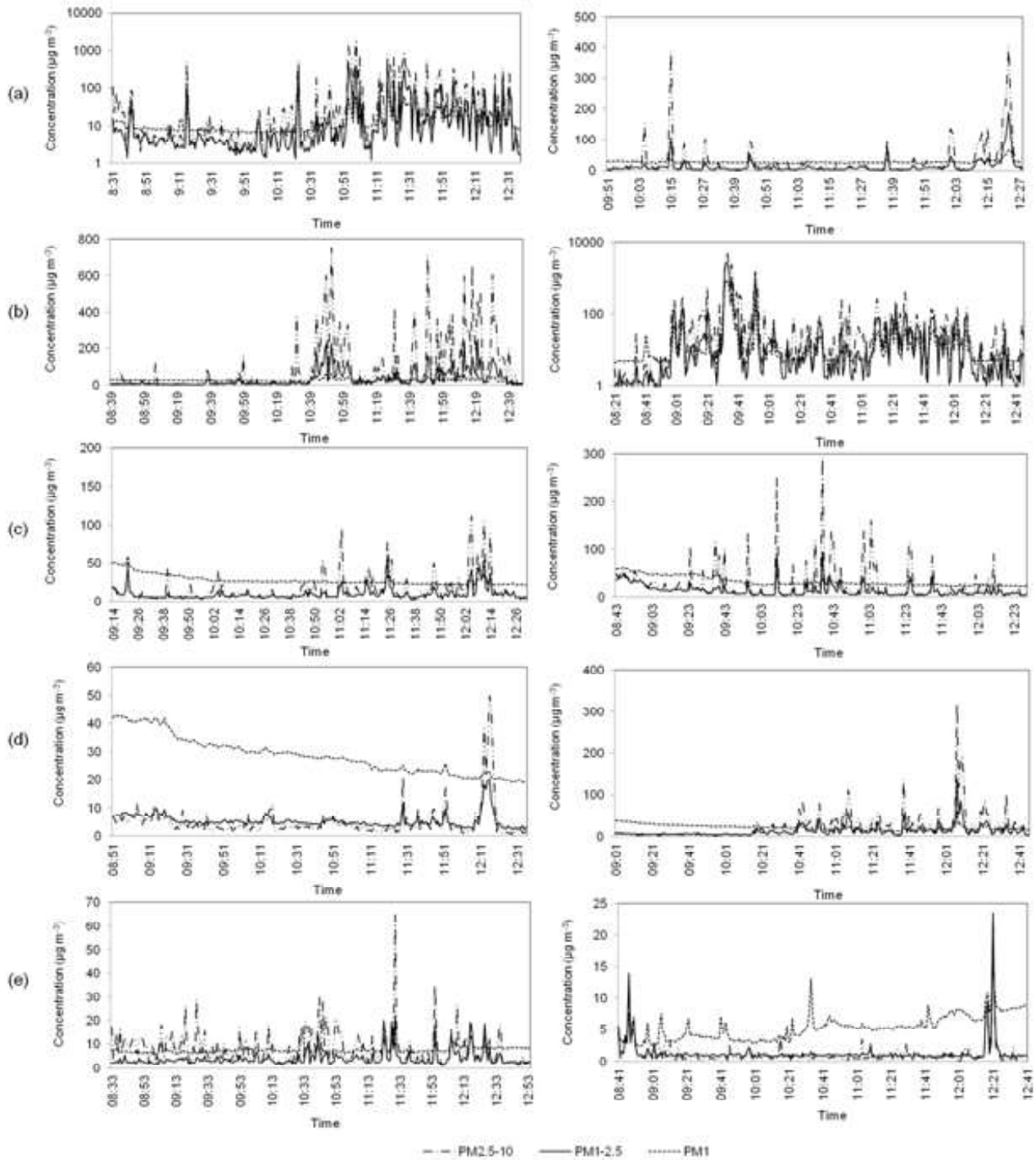


Fig. 5 : Particulate matter profile; (a) 400 mRL, (b) 412 mRL, (c) 448 mRL, (d) 460 mRL and (e) 580 mRL

PROFILE PARTICULATE MATTER GENERATED AT HIGHER DEPTHS IN OPENCAST MINES

During mining, the average contribution of $PM_{2.5-10}$, $PM_{1-2.5}$, $PM_{1-2.5}$ and PM_1 varied from 31 to 61 %, 18 to 26 % and 13 to 49 % respectively (Fig. 7). However, background concentration of $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 were 6 to 8 %, 11 to 16 % and 77 to 83 % respectively (Fig. 4). This further shows

that mining activity generates more coarse particles than fines. Earlier studies (Aneja et al. 2012; Onder and Yigit 2009) have also reported that mining results in generation of particles predominantly in coarse sizes.

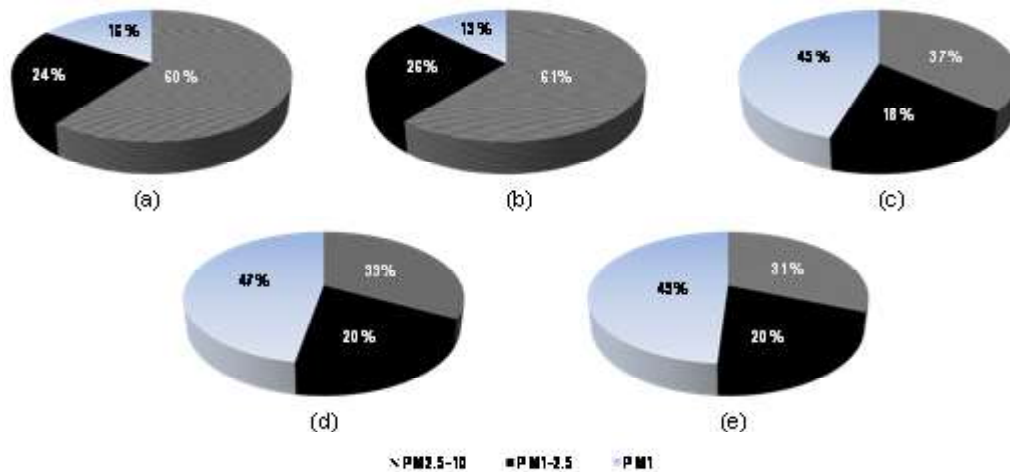


Fig. 7: Proportion of $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 concentration during mining; (a) 400 mRL, (b) 412 mRL, (c) 448 mRL, (d) 460 mRL and (e) 580 mRL

With decrease of depth, the dominance of $PM_{2.5-10}$ is reversed with PM_1 concentration becoming higher than $PM_{2.5-10}$ and $PM_{1-2.5}$. Near the source (400 and 412 mRL), $PM_{2.5-10}$ and $PM_{1-2.5}$ contributed 60 – 61 % and 24 – 26 % respectively to the particulate matter concentration in air. With decrease of depth, $PM_{2.5-10}$ and $PM_{1-2.5}$ contribution gradually decreased to 31 – 37 % and 18 – 20 % respectively. However, contribution of PM_1 increased from

13 – 16% at source to 45 - 49 % with decreasing depth. In the present study the source was located at the bottom two benches of the mine. As particles travel away from the source to higher levels, coarse particles ($PM_{2.5-10}$ and $PM_{1-2.5}$) settle faster than fine (PM_1) particles. Therefore, PM_1 fraction in airborne particulate matter during mining increases with increase of height of benches (Figs. 7&8).

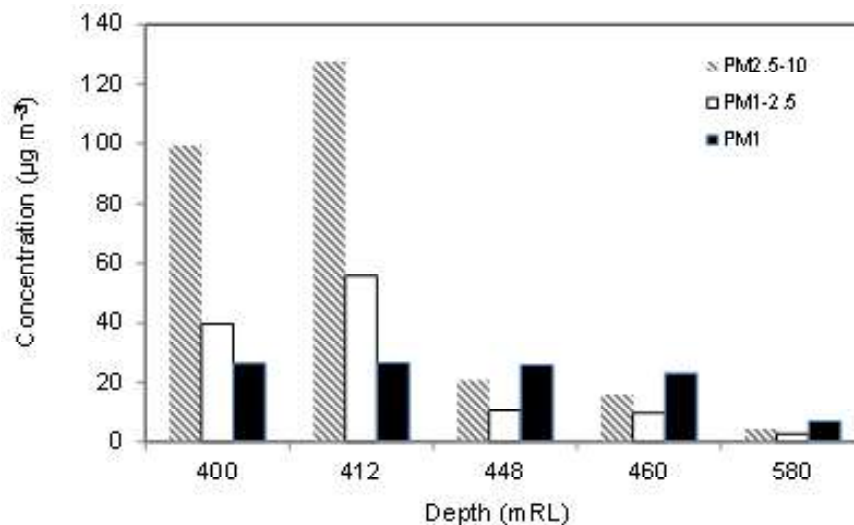


Fig. 8 : Concentration of particulate matter during mining

The mining activities were being carried out in 400 and 412 mRL. As a result, incremental particulate matter concentration due to mining at 412 mRL consists of a combination of particulate matter generated due to mining at 412 mRL and a fraction of particulate matter generated due to mining at 400 mRL. Therefore, the concentration of particulate matter at 412 mRL is higher than particulate matter concentration at 400 mRL (Fig. 8).

Profile of incremental particulate matter concentration with depth

Mining activity at 400 mRL contributes a part of emission generated at this level to 412 mRL, making the concentration of particulate matter at 412 mRL the highest inside the mine. At any location above 412 mRL, no mining activity was present and therefore the concentration of

particulate matter above 412 mRL decreased with height. Therefore, to find the role of depth on particulate matter concentration, 412 mRL has been taken as the source location. From the surface (580 mRL), this is located at a depth of 168 m. Thus the study is equivalent to a mine where the source is located at 168 m depth and the particulate matter concentrations are measured at 168 m (412 mRL), 132 m (448 mRL), 120 m (460 mRL) and 0 m (580 mRL) depth. On day 1, incremental concentrations (measured concentration – background concentration) of $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 from mining decreased from 120.6 to 6.99 $\mu g m^{-3}$, 38.59 to 2.84 $\mu g m^{-3}$ and 16.85 to 2.00 $\mu g m^{-3}$ respectively, from a depth of 168 m to surface. On day 2, $PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1 concentrations decreased from 133.44 to 0.96 $\mu g m^{-3}$, 70.19 to 1.05 $\mu g m^{-3}$ and 23.66 to 3.48 $\mu g m^{-3}$ respectively (Figs. 9a, 9b, & 9c).

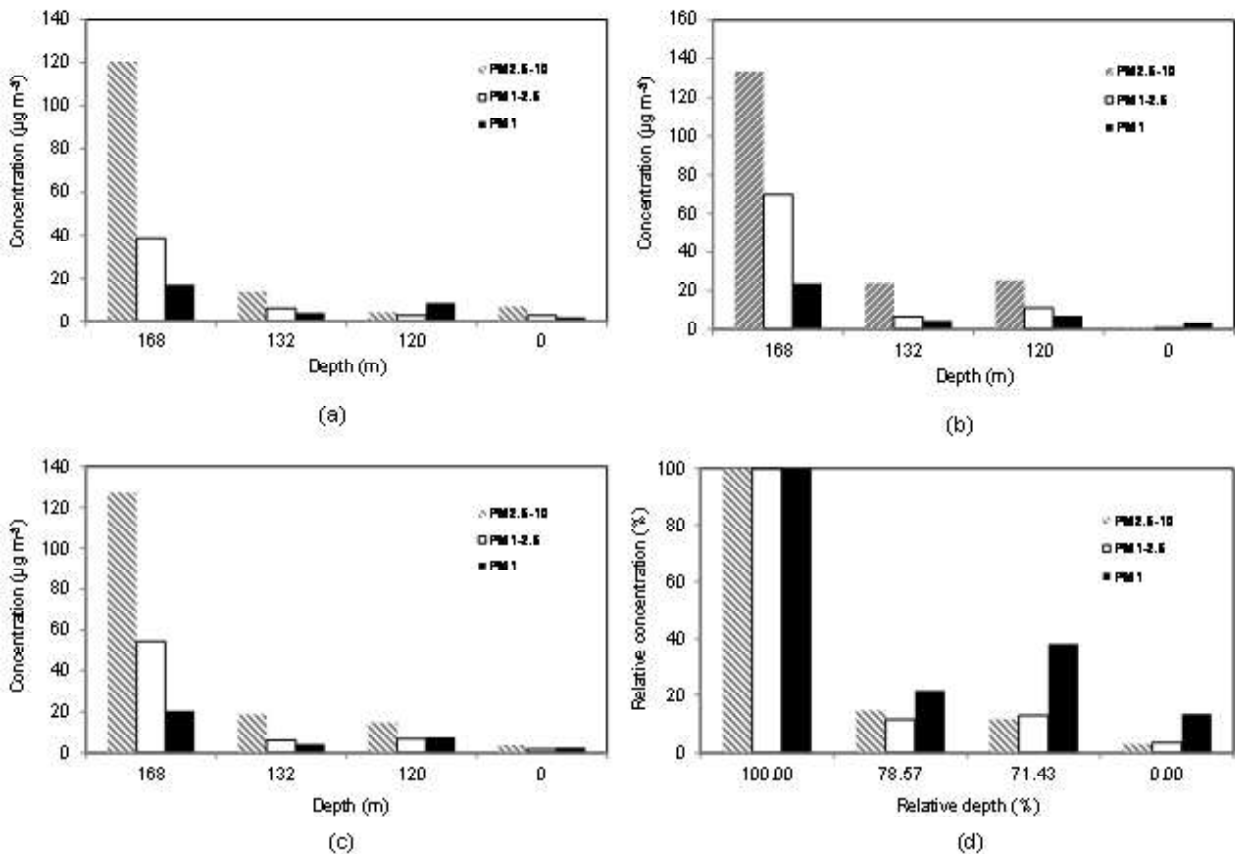


Fig. 9 : Particulate matter concentration at different depths during mining; (a) 1stset; (b) 2ndset; (c) Average of 1st and 2ndset; (d) Average of 1st and 2ndset in terms of relative depth and concentration

PROFILE PARTICULATE MATTER GENERATED AT HIGHER DEPTHS IN OPENCAST MINES

CONCLUSIONS

Background particulate matter concentration at the mine was very low, with the average concentration varying from 0.4-2.1 $\mu\text{g m}^{-3}$, 0.8- 4.1 $\mu\text{g m}^{-3}$ and 4.1-21.5 $\mu\text{g m}^{-3}$ for $\text{PM}_{2.5-10}$, $\text{PM}_{1-2.5}$ and PM_1 respectively. As expected, mining resulted in increase of particulate matter concentration in air. Near the source at 400 and 412 mRL, $\text{PM}_{2.5-10}$, $\text{PM}_{1-2.5}$ and PM_1 concentration during mining increased by a factor of 93.67-195.42, 18.40-41.84 and 0.76-5.92 of respective background concentration. However, due to faster settling of coarse particles, this was significantly lower at 448, 460 and 580 mRL which are away from the source and located at higher elevations. At these locations, the increase of $\text{PM}_{2.5-10}$, $\text{PM}_{1-2.5}$ and PM_1 concentration over background concentration varied by a factor of 8.92-13.03, 1.54-2.71 and 0.20-0.67 respectively.

Background concentration consisted of significantly higher contribution (77 to 83%) of fine particles (PM_1) than coarse particles ($\text{PM}_{2.5-10}$ and $\text{PM}_{1-2.5}$ varied from 6 to 8 % and 11 to 16 %, respectively) because of low settling velocities of fine particles that allow them to remain airborne for long duration. Emissions from mining changed this proportion with dominance of the coarse size particles in air due to generation of higher quantity of it. During mining, the proportion of $\text{PM}_{2.5-10}$, $\text{PM}_{1-2.5}$ and PM_1 varied from 31 to 61 %, 18 to 26 % and 13 to 49 %, respectively. A distinct variation of share of particulate matter of different sizes during mining between locations near the source and that are away from the source could be observed. The coarse particles ($\text{PM}_{2.5-10}$ and $\text{PM}_{1-2.5}$) in air decreased from 60 – 61 % and 24 – 26 % near the source (400 and 412 mRL) to 31 – 37 % and 18 – 20 % away from the source (448, 460 and 580 mRL). In contrary, PM_1 increased from 13 – 16% to 45 - 49 %. Near the source, higher concentration of $\text{PM}_{2.5-10}$ and $\text{PM}_{1-2.5}$ than PM_1 is the result of generation of coarser particles during mining. As a result of higher settling rate of coarse particles, its contribution to particulate matter level in air decreases with increasing distance from the source and therefore, PM_1 share increases.

The authors propose more studies of this type that measures the changing concentration of different sizes of particulate matter as they travel to higher benches from the source at the deeper parts of the mine. A relationship between depth and concentration may be developed.

REFERENCES

- Aneja, V. P., Isherwood, A., and Morgan, P. (2012). Characterization of particulate matter (PM_{10}) related to surface coal mining operations in Appalachia. *Atmosphere Environment*, 54, 496-501.
- Chakraborty, M. K., Ahmad, M., Singh, R. S., Pal, D., Bandyopadhyay, C., and Chaulya, S. K. (2002). Determination of the emission rate from various open-cast mining operations. *Environmental Modeling & Software*, 17, 467-480.
- Chaulya, S. K. (2004). Assessment and management of air quality for an opencast coal mining area. *Journal of Environmental Management*, 70, 1-14.
- Chaulya, S. K., Chakraborty, M. K., Ahmad, M., Singh, R. S., Bandyopadhyay, C., Mondal, G. C., and Pal, D. (2002). Development of empirical formula to determine emission rate from various opencast coal mining operations. *Water, Air and Soil Pollution*, 140 (1-4), 21-55.
- Ghose, M. K. (2007). Opencast coal mining in India: Development of emission factors and quantification of mine dust emissions. *Environmental Quality Management*, 17 (2), 51- 58.
- Ghose, M. K., and Majee, S. R. (2001). Air pollution caused by opencast mining and its abatement measures in India. *Journal of Environmental Management*, 63 (2), 193-202.
- Grimm. (2010). Operation manual of Portable Laser Aerosol spectrometer and dust monitor (Model 1.108/1.109). GRIMM Aerosol Technik GmbH & Co. KG, Ainring, Germany.
- Onder, M., and Yigit, E. (2009). Assessment of respirable dust exposures in an opencast coal mine. *Environmental Monitoring and Assessment*, 152, 393-401.
- Spectrum. (2010). Operation manual of Watchdog 2000 series Portable Weather Station. Spectrum Technologies, Inc., USA.
- Tecer, L. H., Suren P., Alagha O., Karaca F., Tuncel G. (2008). Effect of meteorological parameters on fine and coarse particulate matter mass concentration in a coal mining area in Zonguldak, Turkey. *Journal of the Air & Waste Management Association*, 58, 543 - 552.
- Trivedi R., Chakraborty M. K., and Tewary B. K. (2009). Dust dispersion modelling using dust model at an opencast coal project of Western Coal-fields Limited, India. *Journal of Scientific and Industrial Research*, 68, 71-78.
- Trivedi, R., Chakraborty M. K., and Tewary B. K. (2011). Generation and dispersion of total suspended particulate matter due to mining activities in an Indian opencast coal project, *Monitoring, Control and Effects of Air Pollution*, Prof. Andrzej G. Chmielewski (Ed.), ISBN: 978-953-307-526-6, InTech.
- Zhang, X., Chen, W., Ma, C., Zhan, S. (2013). Modeling particulate matter emissions during mineral loading process under weak wind simulation. *Science of the Total Environment*, 449, 168-173.

Sustainable Development Goals vis-à-vis Resource Dimensions of a Mine : An Indian Case Study

Pukhraj Nenival*

INTRODUCTION

In last few years several attempts have been made to make the mining operations 'sustainable' in addition to safe and eco-friendly. 'The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015', provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries - developed and developing - in a global partnership'. The 17 SDGs in place since then, entire mining operation chain had reoriented its aim to manage their environmental and social impacts, optimum utilization of 'resources', together with protect the health of their workers, achieve energy efficiencies, respect and support human rights, provide opportunities for decent employment and foster economic development.

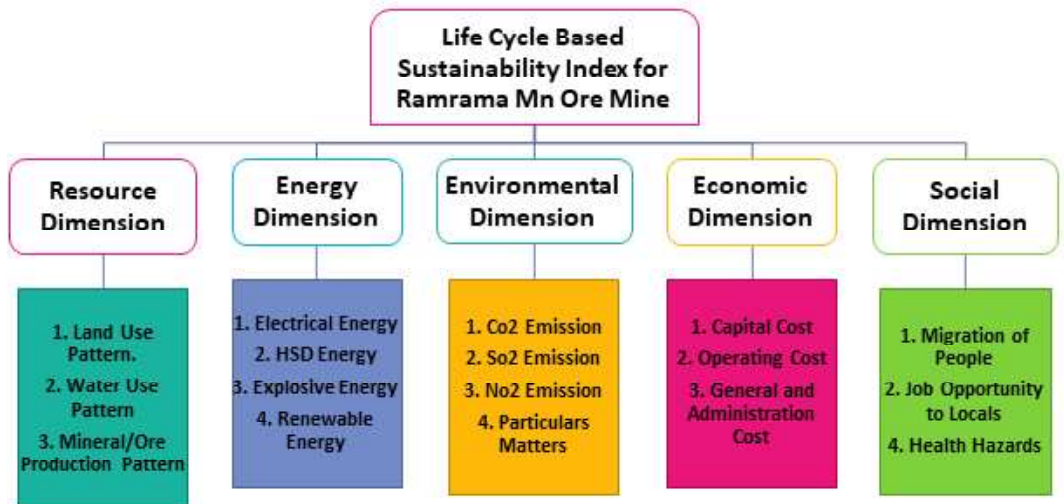
In India several challenges are faced in respect of 'resource dimension' which directly contribute to – environmental degradation (deforestation), displacement of populations from their ancestral homeland, worsening economic and social inequality (due to migration, skill gap among local population, poor education infra), armed conflicts, and increased risk for many health problems (in inaccessible mining areas).

RESOURCE DIMENSIONS & LIFE CYCLE ASSESSMENT

Under 'resource dimensions' SDG 6 – Clean Water and Sanitation; SDG15 – Life on Land: Mine development requires access to land and water presenting significant and broad landscape

impacts that must be responsibly managed, SDG 9 - Infrastructure, Innovation, and Industrialization: Mining can help drive economic development and diversification through direct and indirect economic benefits, the development of new technologies and by spurring the construction of new infrastructure for transport, communications, water and energy have been addressed. The very existence of any mine, its operation being solely influenced by the 'reserves of ore' is another important component of 'resource dimension. Figure 1, presents the role of resource dimension as a part of 'Life Cycle Assessment' and in the following discussions these have been presented aided by a case study of one of the Manganese mines of India.

Life cycle Assessment (from cradle to grave for any product, in this case ROM from mine to the end use of Mn in steel etc), each industry has variation in sustainability indices and may vary across industry and organization, for the case of Ramrama Mn Ore Mine various sustainability indices has been identified and developed as per mining condition considering Techno-Socio parameters.



* Research Scholar. AKS University, Satna (MP)

CASE STUDY

The various Sustainable Development Goals were studied in respect of this manganese mine located in a very ecologically fragile environment in the district of Balaghat. The present paper focused on the Life Cycle Based Sustainability Index for Ramrama Mn Ore Mine with special reference to Resource Dimensions. The description in this paper also cover the geographical location, geological set up of the mine.

Ramrama Mn Ore Mine

This mine is situated in rural area of Balaghat district of Madhya Pradesh having lease area of 43.086 Hectare for the mining of manganese ore. Details of mine is as following-

TOPOGRAPHY

Topographically the lease area has a gentle rolling

topography. The highest and lowest elevation are 342m and 336m, thus resulting difference in elevation is about 6m. the gradient of the area is towards the west, meeting in to Mahadeo nala, since the area has been worked more than six decades hence development like pits/huts/roads/dumps management/office set up degraded the natural topography and their location has been shown on plan, majority of area is agricultural.

REGIONAL GEOLOGY

The Manganese deposits of M.P. are associated with early Proterozoic gneiss and schist belt of the Sausar Group. Sausar series encompassing phyllite, schist, gneisses, crystalline limestone/marble and calc-silicate/granulites and associated Manganese ore deposits of central India. Mansar phyllite and muscovite schist/gneiss having Manganese horizon at bottom, middle and top of the formation. Mineral of Sausar Group is- Hausmanite, Verdenburgite, Jacobsite, Braunite, Holandine and Bixbyte.

Stratigraphic Sequence of Sausar Group

Period	Formation	Lithounits
Recent	Unconformity	Alluvium
	Intrusive	Pegmatite and Vein Quartz
	Bichua Fm.	Dolomitic Marble calc-silicate rocks, Biotite-Muscovite Schist, Sillimanite Bearing Quartz-Biotite-Granulites.
Prterozoic	Chorbaoli Fm.	Garbet- Sturoilite-Quartz-Muscovite Schist, Micaceous and Cherty Quartzite locally with garnet and magnetite.
	Mansar Fm.	Mn ore-I and Gondite-Muscovite Schist Mn Ore-II, Schist Mn Ore-III with Gondite
	Lohangi	Dolomite marbles with lenses of Mn ore calc- silicate rocks, calc-granulites, Quartz-Biotite Granulites and Gneisses
Archean	Tirodi	Disconnformity
	Biotite	Biotite Gneiss, Migmatite, Tonalite,
	Gneiss	Gneiss, Corderite Gneiss, Amphibolites.

LOCAL GEOLOGY

Entire area has been explored by 3 no of pit, whereas pit no 1&2 is running as Open cast and pit no 3 is running as Underground pit. By this exploitation we have found that

upper surface is covered with alluvium. Hang-wall is belong to Chorbaoli formation (Quartzite, Quartz-Mica Schist) and Footwall is belong to Mansar formation (Muscovite-Biotie Schist and Quartz-Mica Schist). The lens of Mn ore is present in-between Chorbaoli and

SUSTAINABLE DEVELOPMENT GOALS VIS-À-VIS RESOURCE DIMENSIONS OF A MINE : AN INDIAN CASE STUDY

Mansar formation. Manganese mineral we found here is- Braunite, Rhodonite, Spessertite.

General strike of the ore body is N61°W and average dip is 55°N. At central part N-S Dipping is also seen in U/G section. Pegmatite intrusion took place on footwall side which traversed Mn ore from Footwall to Hang-wall.

Entire area has been divided into three parts-

1. Western Part
2. Central Part
3. Eastern Part

1. Western Part- From geological point of view, the western part has undergone polyphase folding and neotectonism. As a result, the maximum thickness of Mn ore beds varies between 1 m to 10m on the limbs of the fold.

2. Central Part- This area has been worked out for opencast development as Pit-2 and presently the ore body is exposed at the pit bottom mRL-300 (280m) and lateral length has been considered in 10-25 m lateral influence.

3. Eastern Part- The area has been worked out for O/c development as Pit-1 was worked from mRL-340 m to 295 m, further mineralization has been explored with old bore holes and outcome of exploration has been proved for non-mineralization up to UPD and UPL of the area.

MODE OF OCCURRENCE & CONTROL OF MINERALIZATION

Manganese mineralization associated with sausar group of rocks has been considered as metamorphosed syngenetic type owing to their intimate association with Quartz-Muscovite Schist of Mansar formation

Ramrama deposits occur as narrow repeated bands hosted within "Tirodi-Biotite Gneiss" again in close association with thin layers of Quartz-Mica Schist.

LITHOLOGY

Soil- Entire area covered with alluvium
Muscovite-Biotite Schist
Mn ore- Braunite, Rhodonite, Spessertite
Muscovite-Quartz Schist
Pegmatite

STRUCTURE

The Sausar series rocks are known to have undergone three phases of folding. Folding in Strike direction- Minor and repeated folding Folding in Dip direction- Tight folding forming Anticline and Syncline form of fold and overturned fold Shear direction- N50°E, containing calcareous material. Plunge direction- E-W dip- 30-35°

RESOURCE DIMENSION

As stated in Figure 1, resource dimension had a significant role in addressing the SDGs. For the industry the like Mining, There are mainly three resource dimensions –

- Land,
- Water and
- Mineral reserves

Availability of land and its proper utilization is a matter of concern in present context and also influence the future of mining industry/ The mining industry requires land for mining, dumping of Over Burden/waste, creating stores for engineering material, stores for HSD (a licensed premises under Indian Explosive Rules 2008), and infrastructures (like workshop area, office buildings, statutory buildings like First Aid Room, Vocational Training Centre, Creche, Cap Lamp Room, Record Room, trainees hostel, residential colony etc), Magazines to store explosives, ore handling facilities, stock yards etc. Land use pattern is a key for sustainable mining future, land acquisition become a challenge for mining industry because of its adverse impact on environment.

LAND USE PATTERN

Land use pattern refers to the distribution and arrangement of different types of land uses in a particular area. In the context of the mining industry, land use patterns are significantly influenced by the exploration, extraction, and processing of minerals. The following are key aspects of land use patterns associated with the mining industry:

EXPLORATION AREAS

- Prior to mining activities, exploration areas are designated to identify potential mineral deposits.
- These areas may involve geological surveys, core drilling, and other exploratory methods.

- Exploration activities often cover large expanses of land, and their patterns depend on the type of minerals being sought.

MINING OPERATIONS

- Mining activities involve the extraction of minerals from the earth, and the layout of mining operations varies based on the geological characteristics of the deposit.
- Open-pit mining, underground mining, and mountaintop removal are common methods, each with its own distinct land use pattern.
- Infrastructure like roads, processing plants, and waste disposal areas also contribute to the overall land use pattern.

REHABILITATION AND RECLAMATION

Rehabilitation refers to the restoration of land that has been disturbed by mining activities. It involves the implementation of measures to improve soil quality, promote vegetation growth, and address any other ecological disruptions caused by mining. Whereas Reclamation refers to Reclamation is the process of converting mined land into a useful and sustainable form, often for purposes like agriculture, forestry, or recreational activities. It goes beyond ecological restoration to create a functional and economically viable landscape.

- After the exhaustion of a mineral deposit, mining companies are often required to rehabilitate and reclaim the land.

Year	Unit	Area under Mining	OB Dumps	Mineral Storage	Workshop/ Administration Building	Roads	Greenbelt	Other	Total
2012-13	Hect	10.971	8.416	0	1.032	0.576	0	0.005	21.000
2013-14	Hect	11.315	11.428	0.36	1.052	0.576	0.06	0.35	25.141
2014-15	Hect	11.315	11.428	0.36	1.052	0.576	0.06	0.35	25.141
2015-16	Hect	11.135	11.3186	0.36	1.052	0.576	0.06	0.41	24.912
2016-17	Hect	11.135	11.3186	0.36	1.052	0.576	0.06	0.41	24.912
2017-18	Hect	11.135	11.3186	0.36	1.052	0.576	0.06	0.41	24.912
2018-19	Hect	11.135	11.3186	0.36	1.052	0.576	0.06	0.41	24.912
2019-20	Hect	11.135	11.3186	0.36	1.052	0.576	0.06	0.41	24.912
2020-21	Hect	11.450	13.411	0.10	1.052	0.576	0.06	0.20	26.849
2021-22	Hect	11.450	13.411	0.10	1.052	0.576	0.06	0.20	26.849
2022-23	Hect	11.450	13.411	0.10	1.052	0.576	0.06	0.20	26.849

- This process aims to restore the landscape to a condition close to its original state or to an alternative beneficial land use, such as agriculture or forestry.

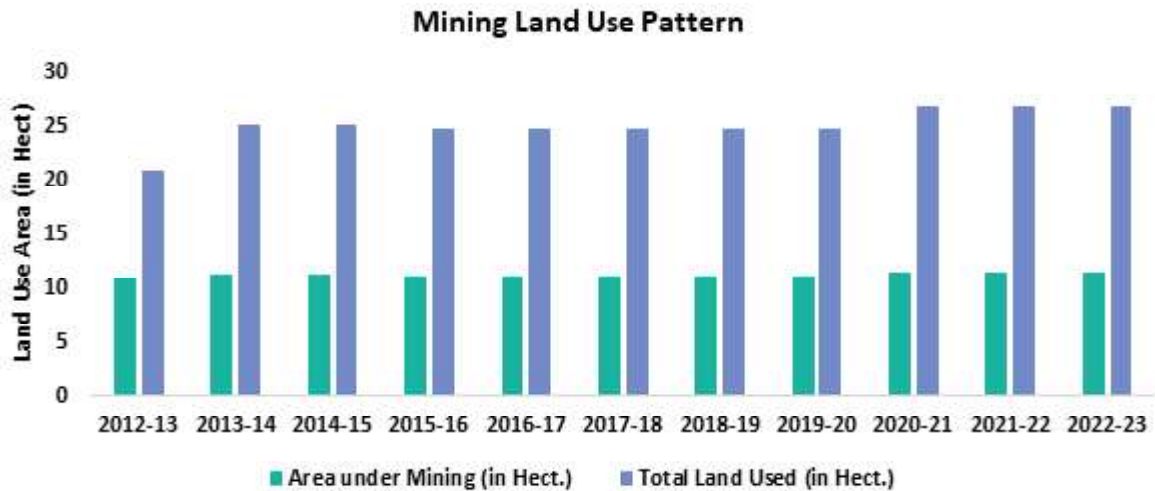
With above stated land use pattern, there is constant need of land for the purpose of mining, storage of soil and OB for reclamation to achieve the closure of mine beyond to that land required for storage of produced minerals,

infrastructure like workshops/ administration building, roads (land required for road development is flexible as the lead of transportation plays a crucial role in cost control and pollution control. Greenbelt of the pollution control in and around mining area and the processing plant is required for the control over fugitive dust control and sustainability. Land use pattern for the Ramrama Mn Ore Mine is as for the one decade.

SUSTAINABLE DEVELOPMENT GOALS VIS-À-VIS RESOURCE DIMENSIONS OF A MINE : AN INDIAN CASE STUDY

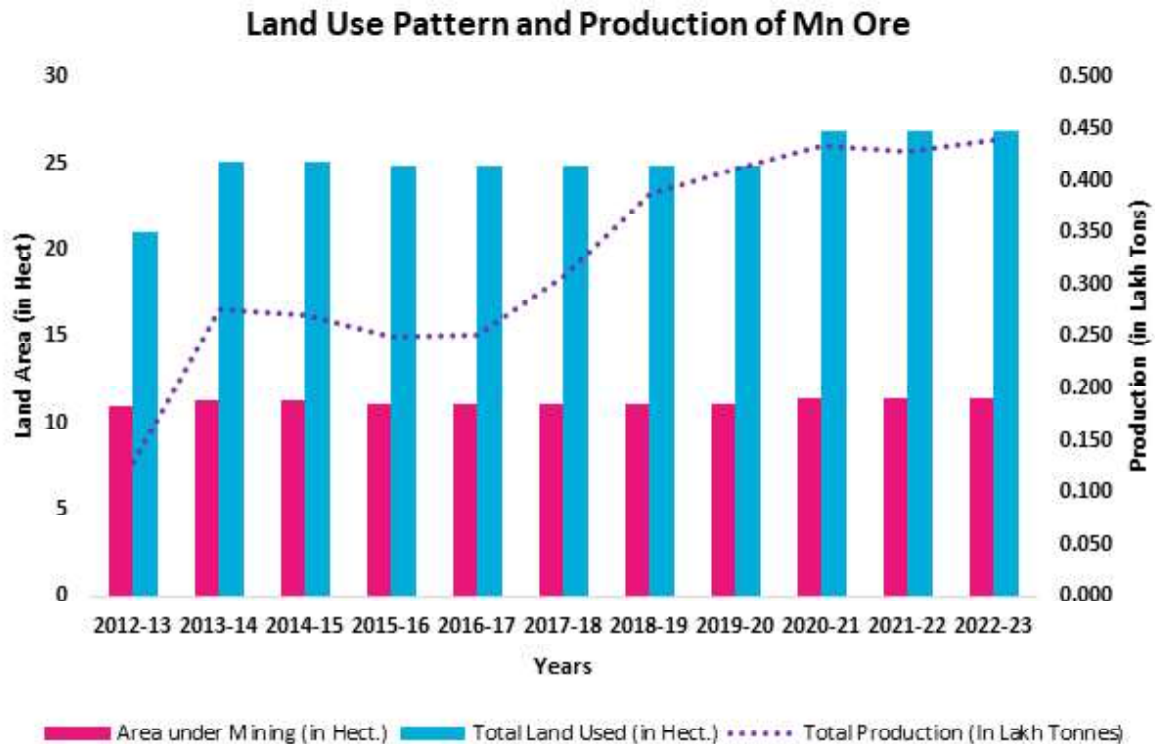
To understand the sustainability of Ramrana Mn ore mine various components of land use pattern is compared with total land use, as optimization of Land resource is very crucial for any mining industry and its proper use reflects

the sustainability of land resource. Proper Surface land utilization also have positive impact on Environment pollution control & Resource utilization. Land used for mining activity in Ramrama Mn Ore Mine as below-



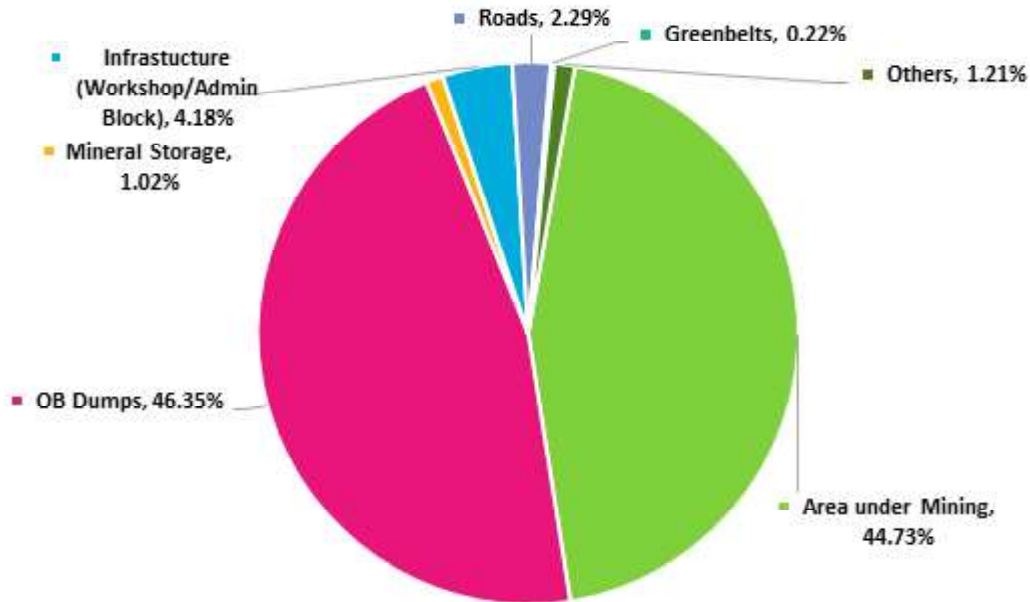
With above comparison graph, it is understood that in last one decade, maximum and minimum year wise land

used for mining are 52.24% in the year of 2012-13 and 42.65 % in the years from 2020-23 constantly respectively.



Whereas minimum and maximum production achieved in the year of 2012-13 and 2022-23 respectively. Which

shows the trend of optimum land utilization pattern achieved during the year of 2020-23 with maximizing the production.



Average percentage wise land area utilization for various mining infrastructures are shown in pie chart for the last one decade. Maximum land area is utilized for OB dumps for the production of Mn ore.

- Dust suppression is another significant use of water in mining operations, especially in open-pit mining.

WATER USE PATTERN

WASTE MANAGEMENT

Water is a crucial resource in the mining industry, utilized for various purposes throughout the mining cycle. The water use pattern in mining involves several stages:

- Tailings, the byproducts of ore processing, often require water management to prevent environmental contamination. Tailings dams and ponds may be used for storage.

EXPLORATION AND DRILLING

REHABILITATION

- Water is used for drilling during exploration activities to extract core samples and assess mineral potential.

- Water is crucial in the rehabilitation and reclamation process to establish vegetation and restore ecosystems.

MINING OPERATIONS

- Water is a key component in mineral processing, used for grinding, flotation, and separation of minerals from ore.

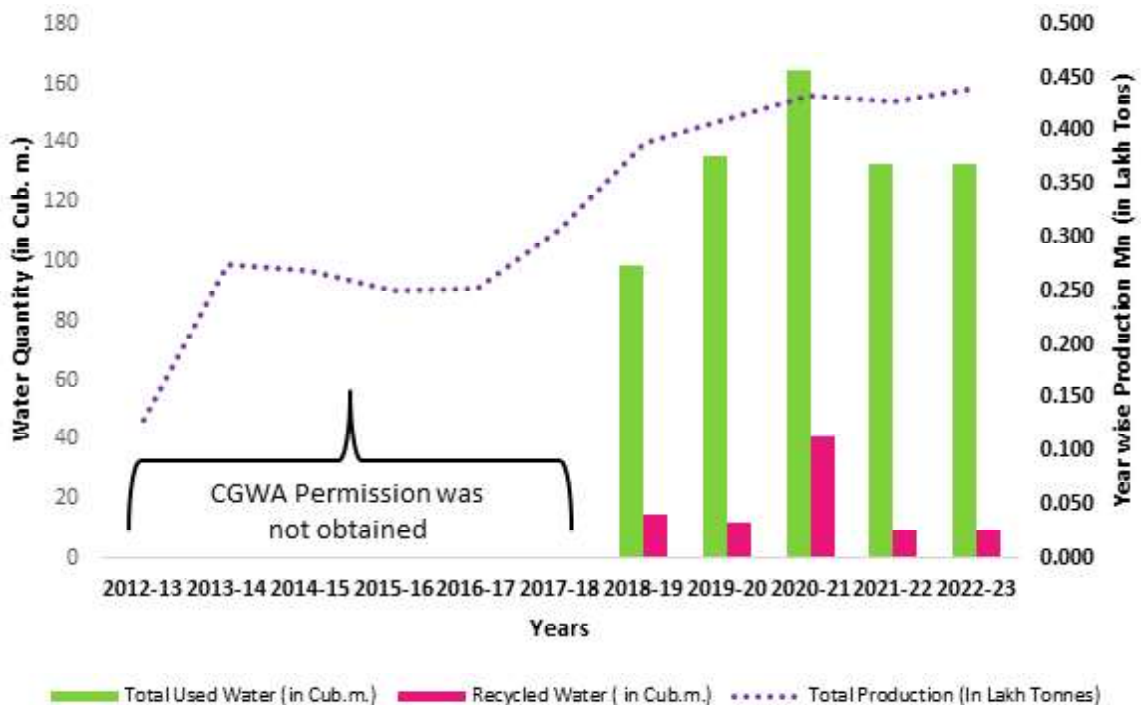
Beside to stated above major water resource utilization component, in Ramrama Mn ore mine water used for workshop/Garages, washing plants/ Processing Plant, Colony & Offices and other areas such as Agriculture, dust suppression, green belt water sprinkling, soak pits and recycles water use pattern for the last one decade is as tabulated-

SUSTAINABLE DEVELOPMENT GOALS VIS-À-VIS RESOURCE DIMENSIONS OF A MINE : AN INDIAN CASE STUDY

Year	Unit	Workshop/ Garages	Washing Plant/ Processing Plant	Colony & Offices	Others	Total
2012-13	0	0	0	0	0	0
2013-14	0	0	0	0	0	0
2014-15	0	0	0	0	0	0
2015-16	0	0	0	0	0	0
2016-17	0	0	0	0	0	0
2017-18	0	0	0	0	0	0
2018-19	Cu. Mtr.	0	4	12	82.5	98.5
2019-20	Cu. Mtr.	0	4	12	113.5	135.5
2020-21	Cu. Mtr.	0	4	12	148.5	164.5
2021-22	Cu. Mtr.	0	4	12	116.5	132.5
2022-23	Cu. Mtr.	0	4	12	116.5	132.5

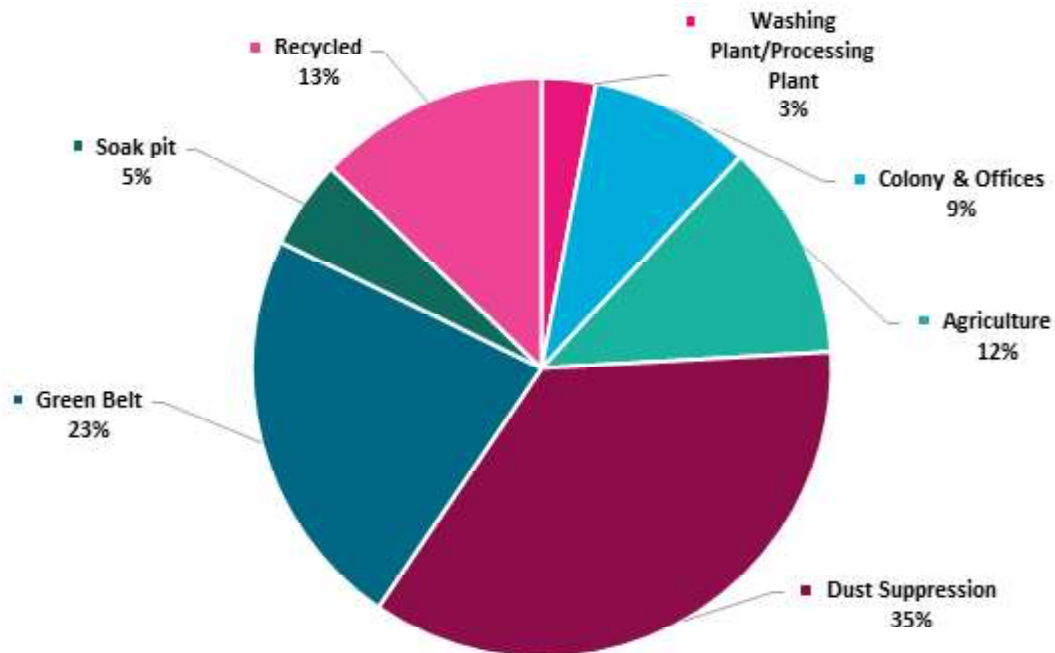
With reference to above table, it is stated that from the year 2012- 2018, CGWA (Central Ground Water Authority) permission was not obtained to extract the ground for industrial use. Permission for ground water extraction and

use is obtained in the year of 2018 and from proceeding year ground water was utilized for industrial purpose and their quantity and utilization with recycled water quantity are shown in Table.



With reference to above graph, it is understood that the total water used quantity is constant along with recycled water quantity in last two year, where as Mn ore production is also constant. Optimized Mn ore production and water utilization reflects sustainability of industrial water utilization. To understand the water, use in water activity of Ramrama Mn Ore mine. An pie chart is created showing the percentage of water utilization and recycled water. The decrease in industrial water quantity utilization is result

of production from UG mining, as in opencast mining water was used for dust suppression, accumulated water was need to be discharge out from sump area for the development of mine, as conversion from opencast mine to underground mine results in less discharge for accumulated water thus resulting less recycling of water. Ultimately resulting in less ground water uses as shown in Table. The percentage of ground water use for industrial purpose are shown as-



RESERVE FOR MINING PRODUCTION

Reserves in the context of the mining industry refer to identified and economically viable deposits of minerals that can be extracted profitably. Reserves are categorized into proven and probable reserves based on the level of geological confidence. The reserve estimation involves detailed geological assessments and economic feasibility studies. Some key points about reserves in the mining industry include:

PROVEN RESERVES

- Proven reserves are depositing that geological surveys and sampling have confirmed with a high degree of certainty.
- These are economically recoverable under current market conditions and with existing

technology.

PROBABLE RESERVES

- Probable reserves are deposits that are likely to be economically viable based on geological evidence and preliminary economic assessments.
- The level of confidence in probable reserves is lower than proven reserves.

MINING PLANNING AND DEVELOPMENT

- Mining companies use reserve estimates to plan and develop mining operations, determining the scale and feasibility of the project.

SUSTAINABLE DEVELOPMENT GOALS VIS-À-VIS RESOURCE DIMENSIONS OF A MINE : AN INDIAN CASE STUDY

FINANCIAL IMPLICATIONS

- Reserves are essential for financial planning and reporting, influencing investment decisions and the valuation of mining companies.

reserve estimation are integral components in the sustainable development and responsible management of the mining industry. It involves a delicate balance between resource extraction, environmental protection, and social responsibility. The following is the production statistics of Ramrama Mn Ore Mine-

Overall, the land use pattern, water use pattern, and

Year	UG Production (in Tons)	OC Production (in Tons)	UG Waste/OB (in Cub. M)	OC Waste/OB (in Cub. M)
2012-13	426.000	12599.000	-	109942
2013-14	5450.000	22075.000	-	44852
2014-15	3278.000	23675.000	-	45559
2015-16	8024.000	17033.000	-	76115
2016-17	9219.000	16005.000	-	47076
2017-18	19236.000	11655.000	-	40172
2018-19	17010.000	21790.000	-	45660
2019-20	29074.000	12098.000	-	34863
2020-21	28187.000	15162.000	-	53376
2021-22	26972.000	15842.000	-	38439
2022-23	35219.000	8796.000	-	48461

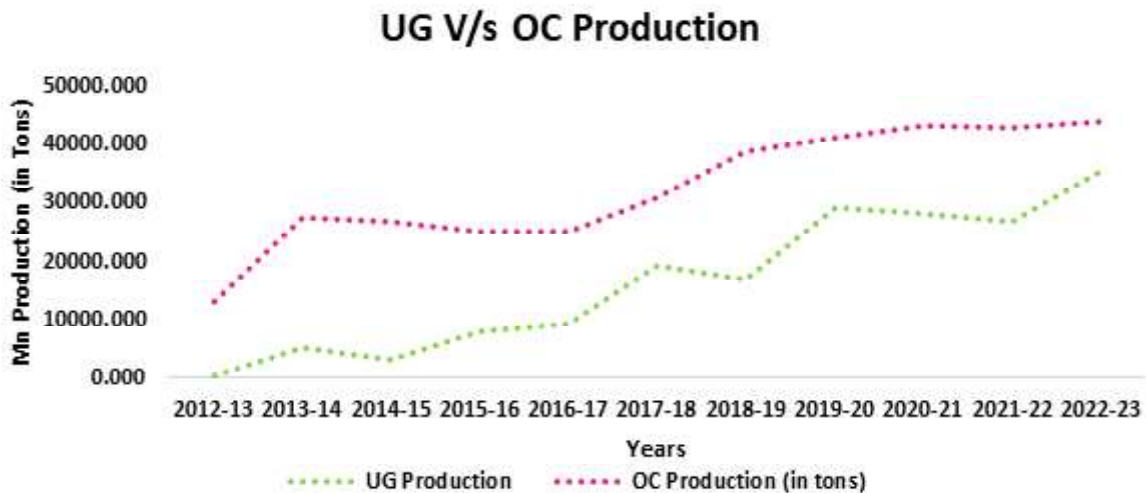


Figure- UG and OC Production of Ramrama Mn Ore Mine

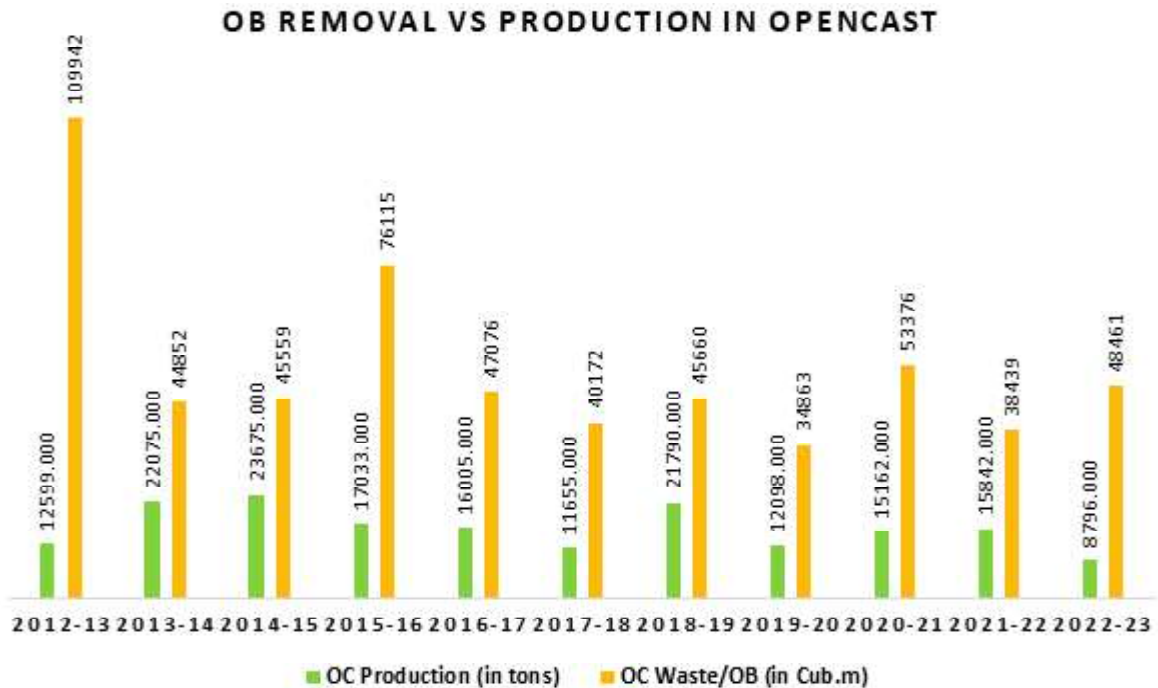


Figure- OB removal and Production of Manganese from OC Mining in Ramrama Mn Mine

OB Removal and Mn production is shown in above Figure..... which depict that average 4 cubic meter of OB was removed for the production of one ton of Mn ore. With mining methodology changes, the removal of OB almost zero, resulting in less disturbance in the natural state of ecology and saving in cost operation and increase in ROM Grade because of less dilution in UG Mining. The problems associated with opencast mining of Mn ore are as following below, which can pose several environmental, social, and economic challenges. some common problems associated with open-cast manganese mining:

ENVIRONMENTAL IMPACT

- **Deforestation and Habitat Destruction:** Open-cast mining often requires clearing large areas of land, leading to deforestation and destruction of natural habitats. This can result in the loss of biodiversity and disrupt ecosystems.
- **Soil Erosion:** The removal of vegetation and topsoil during mining can contribute to soil erosion, leading to the degradation of soil quality and increased sedimentation in nearby water bodies.
- **Water Pollution:** Mining activities may release

harmful chemicals into water bodies, contaminating water sources and affecting aquatic life. Manganese mining, in particular, can introduce manganese compounds into water, impacting water quality.

AIR POLLUTION

- **Dust and Particulate Matter:** The excavation and transportation of manganese ore can generate dust and particulate matter, contributing to air pollution. Inhaling these particles can pose health risks to both humans and animals in the surrounding areas.

HEALTH AND SAFETY CONCERNS

- **Worker Safety:** Open-cast mining involves heavy machinery, explosives, and other potentially hazardous conditions. Ensuring the safety of workers is crucial to prevent accidents and injuries.
- **Community Health:** The release of pollutants into the air and water can have adverse effects on the health of nearby communities, leading to

SUSTAINABLE DEVELOPMENT GOALS VIS-À-VIS RESOURCE DIMENSIONS OF A MINE : AN INDIAN CASE STUDY

respiratory problems and other health issues.

SOCIAL IMPACTS

- **Displacement of Communities:** Mining operations may necessitate the relocation of local communities, disrupting their livelihoods and cultural practices. The resettlement process can lead to social conflicts and challenges in adapting to new environments.
- **Land Degradation:** The physical alteration of landscapes due to mining can impact the traditional land uses of local communities, such as agriculture or grazing.

REGULATORY COMPLIANCE

- **Enforcement of Environmental Regulations:** In some cases, lax enforcement of environmental regulations or inadequate regulatory frameworks can contribute to environmental degradation. Proper monitoring and enforcement are essential to mitigate these issues.

WASTE MANAGEMENT

- **Mine Tailings:** The disposal of waste materials, such as mine tailings, can lead to environmental contamination. Proper waste management practices are crucial to minimize the long-term environmental impact.

GLOBAL MARKET FLUCTUATIONS

- **Price Volatility:** Manganese, like many minerals, is subject to global market fluctuations. Sudden drops in prices can impact the economic viability of mining operations, affecting local economies and employment.

While manganese ore mining, especially through underground methods, presents challenges, there are also potential positive aspects associated with this approach. Here are some positive points in favor of underground manganese ore mining, which reflects the sustainability of Ramrama Mn Ore Mines-

Reduced Environmental Impact:

Underground mining generally has a smaller

environmental footprint compared to open-cast mining. The impact on surface ecosystems, deforestation, and habitat disruption is typically less severe.

Preservation of Surface Land:

Underground mining allows for the preservation of surface land, minimizing the need for large-scale clearing and reducing the visual impact on the landscape.

Improved Safety:

Underground mining can be safer for workers compared to open-cast mining, as it reduces the risk of accidents related to heavy machinery, landslides, and other surface hazards. Geotechnical Studies of Ramrama Mn Ore Mine reveals that the RMR is 80, which is very good for the UG Mine development, with proper mine planning all geological structures can be considered for the development of safe and sustainable mining.

Lower Noise and Dust Levels:

The operation of mining activities underground tends to generate less noise and dust compared to open-cast mining, contributing to a more favorable environment for nearby communities. Ramrama Mn Ore Mine is situated in eco sensitive area, transition from Opencast to Underground mining is resulted in drastically decrease in noise pollution and dust production level.

Resource Recovery Efficiency:

Underground mining methods often result in higher ore recovery rates compared to open-cast mining. This can lead to more efficient use of the resource, reducing the overall environmental impact per unit of ore extracted.

Stable Production Regardless of Weather Conditions:

Underground mining is less susceptible to weather conditions that can disrupt open-cast mining activities, such as heavy rainfall or extreme temperatures. This stability in production can be beneficial for meeting market demands.

Less Surface Disruption and Subsidence:

Underground mining minimizes surface disruptions and the risk of land subsidence, helping to maintain the stability of the surrounding environment and infrastructure.

Reduced Rehabilitation Requirements:

The rehabilitation of mined areas may be less extensive for underground mining operations compared to open-

cast mining. This can result in a faster recovery of disturbed land.

Community Relations:

With less impact on the surface environment, underground mining may lead to better relations with local communities. Reduced disturbance to landscapes and ecosystems can contribute to positive community perceptions.

Resource Efficiency:

Underground mining can be more resource-efficient as it allows for selective mining, targeting higher-grade ore zones. This can lead to more efficient use of energy and resources in the extraction process.

Transition of Ramrama Mn Ore Mine from OC to UG Mining, resulted in Reduced environment impact, land Preservation, Safety enhancement, Noise and dust pollution and improvement in resource recovery efficiency, stable production and further improvement of community relationship, which fulfill the long term goal of achieving sustainability and balance on Production and market supply of Mn ore, keeping in view, the vision of sustainability the adverse impact of Opencast mining is mitigated resulted in development of system which is in favor of environment, ecology and productivity.

CONCLUSION

With the help of life cycle Assessment, each industry has variation in sustainability indices and may vary across industry and organizations. In case of Ramrama Mn Ore Mine various sustainability indices has been identified and developed as per mining condition considering Techno-Economic parameters. The most important indices like Energy Dimension had not only helped in creating awareness amongst the users to adopt new technologies for energy conservation but also identify renewable sources of energy to replace the fossil fuel in phases. Mines have chosen 'solar' as the most popular source of renewable energy for ensuring reduction in conventional sources of electricity (mostly thermal route) for sustainable mining operations. In the today's mining scenario where spiraling cost of fuel bill, thrust on energy use optimally has helped the mines to reduce cost of fuel. Since 'energy' contributes immensely to the growth of the sector vis-a-vis its availability, storage, transmission(in case of electricity), and use has an impact on overall cost of mining also for sustainable mining.

SELECTED REFERENCES

Farjana, S.H, Mahmud, M.A.P and Nazmul Huda, N. (2021) Life Cycle Assessment for Sustainable Mining, Elsevier, <https://doi.org/10.1016/C2020-0-01670-1>.