International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 21, Issue 5 (May 2025), PP 109-115

Comprehensive Assessment of Air Pollution around Opencast Coal Mining Areas: Pollutant Dynamics, Health Impacts, and Dispersion Modeling in Central India

Ghugul Ashutosh Ashok[1], Chitranjan Kumar[2]
[1]Research Scholar, Department of Civil Engineering, Shri Venkateshwara University[2]Assistant Professor, Department of Civil Engineering, Shri Venkateshwara University,

Abstract: *Opencast coal mining remains one of the most pollution-intensive industrial activities, contributing significantly to ambient air degradation through particulate matter, gaseous pollutants, and toxic heavy metals. This study presents an integrated assessment of air pollution in a major opencast coal mining site in Central India. High-resolution data were collected from six strategic monitoring stations (S1–S6) using gravimetric and real-time analyzers, measuring PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, and heavy metals. Spatial analysis via GIS-based interpolation and AERMOD-CALPUFF dispersion modeling revealed critical pollution hotspots near mining pits and haul roads, especially during winter months due to atmospheric inversion. Health surveys involving 150 participants showed a strong positive correlation between pollution levels and respiratory illnesses. Results highlight the urgent need for regulatory interventions, enhanced dust suppression, and adoption of electric mining equipment. The study recommends an integrated pollution control framework combining real-time monitoring, green belt development, and regulatory zoning.*
Keywords: *Opencast coal mining, air pollution, PM10, PM2.5, dispersion modeling, GIS mapping, respiratory health, AERMOD, CALPUFF, Central India*

Date of Submission: 10-05-2025 Date of acceptance: 20-05-2025

I. Introduction

Air pollution resulting from opencast coal mining operations represents a significant environmental and public health challenge, particularly in developing nations such as India where regulatory enforcement is often weak and infrastructure limitations hinder real-time pollution control. Opencast or surface mining, which involves the removal of large quantities of overburden to access coal seams, generates substantial quantities of airborne pollutants including suspended particulate matter (PM_{10} and $PM_{2.5}$), gaseous emissions such as sulfur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), and toxic heavy metals like lead (Pb), arsenic (As), and cadmium (Cd) (Ghose &Majee, 2000; Masto et al., 2015). These pollutants are primarily released during activities such as drilling, blasting, coal excavation, transportation, and coal handling, and are known to adversely impact air quality in and around mining zones (Tiwary & Dhar, 1994).

Particulate matter, particularly the fine fraction $PM_{2.5}$, has been identified as one of the most dangerous air pollutants due to its ability to penetrate deep into the lungs and bloodstream, causing severe respiratory and cardiovascular ailments (WHO, 2018; Gautam et al., 2021). In opencast mining regions, levels of PM_{10} and $PM_{2.5}$ have been consistently recorded above permissible limits prescribed by the Central Pollution Control Board (CPCB) and the World Health Organization, posing elevated risks to mine workers and nearby communities (Maji et al., 2017). In addition to particulates, the release of gaseous pollutants—originating from diesel combustion, use of explosives, and spontaneous oxidation of coal—further degrades ambient air quality and contributes to secondary effects like photochemical smog and acid rain (Singh et al., 2018).

The health implications of such pollution are significant. Several epidemiological studies have demonstrated a strong association between chronic exposure to mining-related air pollution and increased incidences of asthma, bronchitis, chronic obstructive pulmonary disease (COPD), eye irritation, and fatigue among populations residing within a 5 km radius of mining zones (Zhou et al., 2019; Chen et al., 2020). In regions with high levels of $PM_{2.5}$ and NO_x, lung function in both adults and children has shown measurable decline, highlighting the long-term public health burden (Gautam et al., 2021). Despite the existence of environmental guidelines under frameworks such as the National Ambient Air Quality Standards (NAAQS), the Clean Air Act, and regional Environmental Impact Assessment (EIA) protocols, the enforcement and compliance of these regulations remain inconsistent, particularly in remote or illegally operated mining sites (Jharia et al., 2019).

Given this background, there is a critical need to conduct a comprehensive and spatially resolved assessment of pollutant concentrations, source attribution, dispersion behavior, and associated health risks in opencast coal mining regions of India. Recent advances in geospatial mapping and atmospheric dispersion modeling, including tools like AERMOD and CALPUFF, offer the opportunity to visualize pollution spread and identify vulnerable downwind zones (Sharma et al., 2023). Furthermore, integrating environmental data with community health surveys allows for an evidence-based understanding of pollution-health linkages and facilitates the formulation of context-specific mitigation strategies.

This study aims to fill existing research gaps by evaluating air pollution levels around a major opencast coal mining site in Central India using high-resolution pollutant monitoring, GIS-based mapping, and statistical analysis. The findings are expected to inform future regulatory action, enhance public health planning, and contribute to the development of sustainable mining practices in similar ecological and socio-economic contexts.

II. Materials And Methods

2.1 Study Area and Sampling Design

This study was carried out in a major opencast coal mining belt located in Central India, an area known for intensive mining activity and substantial environmental stress. The region comprises a mix of operational mining zones, surrounding residential settlements, agricultural lands, and ecologically sensitive areas. To ensure spatial representativeness and capture pollutant gradients relative to the mining epicenter, six monitoring sites (designated as S1 to S6) were strategically selected. These sites represent varying degrees of exposure—ranging from high-intensity pollution zones within the active mining pit and haul roads to low-exposure background locations situated several kilometers away from direct mining influence. The geographical coordinates of the monitoring network span from approximately 24.1234°N to 24.1500°N in latitude and 82.9876°E to 83.0156°E in longitude. This spatial configuration enabled the study to systematically assess the influence of mining operations on ambient air quality, while also facilitating comparative analysis across different land-use zones and population exposure categories. The selection of sites was further guided by accessibility, prevailing wind direction, and topographic features that influence pollutant dispersion.

2.2 Pollutant Measurement Techniques

To accurately quantify ambient air pollutants in and around the opencast coal mining area, a combination of standardized, high-precision monitoring instruments was deployed at six designated locations. The focus was on measuring both particulate matter—specifically PM_{10} and $PM_{2.5}$—and gaseous pollutants including sulfur dioxide (SO_2), nitrogen oxides (NO_x), and carbon monoxide (CO), along with relevant meteorological parameters such as wind speed and temperature. PM_{10} was measured using a High Volume Sampler (HVS), operating on a gravimetric principle with a 24-hour sampling cycle conducted twice per week. For finer particulates ($PM_{2.5}$), a Fine Particulate Sampler was utilized, also based on the gravimetric method and following the same sampling frequency. Gaseous pollutants were monitored continuously using a real-time Aeroqual Series 500 gas analyzer, which employs electrochemical and non-dispersive infrared (NDIR) sensors to deliver one-minute average concentration readings. Meteorological data, essential for dispersion modeling and temporal trend analysis, were recorded using a Digital Weather Station equipped with an anemometer and thermistor sensors. The details of the instruments, parameters measured, techniques employed, and models used are summarized in Table 1.

Table 1: Monitoring Instruments and Parameters

Instrument	Parameter	Technique	Frequency	Model
HVS	PM10	Gravimetric	24h, biweekly	APM 460 BL
Fine Sampler	PM2.5	Gravimetric	24h, biweekly	APM 550
Gas Analyzer	SO_2, NO_x, CO	Electrochemical/NDIR	1-min avg	Aeroqual 500
Digital Weather Station	Wind, Temp	Anemometer/Thermistor	Continuous	Davis Vantage Pro2

2.3 Health Survey and Data Collection

To evaluate the public health implications of air pollution in the mining-affected area, a structured health survey was conducted among residents and workers within a 5 km radius of the mining site. A total of 150 individuals participated in the survey, encompassing diverse demographic groups including mine workers, residents of the nearby residential colony (S4), agricultural community members (S5), and control group participants from the background site (S6). The questionnaire was designed to capture both self-reported and clinically diagnosed symptoms, particularly focusing on respiratory ailments such as chronic cough, bronchitis, asthma, wheezing, and other health conditions like fatigue, eye irritation, and cardiovascular discomfort. In addition to individual health metrics, information was also gathered regarding occupational exposure, use of protective equipment, frequency of medical visits, and living conditions. The survey data were later correlated with ambient air pollutant concentrations measured at respective locations to identify statistically significant relationships between exposure levels and health outcomes. Additionally, in-depth interviews were conducted with local healthcare providers to validate the survey findings and contextualize the frequency and severity of pollution-related illnesses. This integrated health assessment approach provided valuable insights into the real-world implications of environmental degradation caused by opencast coal mining.

2.4 Spatial and Dispersion Modeling

To analyze the spatial dynamics of air pollution and identify high-risk exposure zones, advanced geospatial and atmospheric modeling techniques were employed. Geographic Information System (GIS) tools, specifically QGIS and ArcGIS, were used to map and interpolate pollutant concentrations across the study area. Inverse Distance Weighting (IDW) interpolation was applied to visualize the spatial distribution of PM_{10} and $PM_{2.5}$, enabling the identification of localized pollution hotspots in relation to mining activity. Additionally, meteorological data including wind speed and direction were layered onto the maps to interpret pollutant dispersion behavior. For a more detailed simulation of pollutant transport and accumulation, two atmospheric dispersion models were utilized: AERMOD and CALPUFF. AERMOD was applied to model short-range dispersion of coarse particulates (PM_{10}), considering terrain features, emission rates, and local meteorological conditions. In contrast, CALPUFF was used for long-range and non-steady-state simulation of gaseous pollutants such as SO_2 and NO_x, accounting for chemical transformation, terrain-induced flow, and atmospheric stability variations. These models helped in validating field observations and projecting pollution spread scenarios under different environmental conditions. The spatial outputs were instrumental in zoning high-risk areas, supporting mitigation planning, and guiding policy recommendations for sustainable mining practices.

III. Results And Discussion

3.1 Ambient Air Quality Analysis

Ambient air quality monitoring across six strategically selected sites revealed significant spatial variation in pollutant concentrations, largely corresponding to proximity and exposure to active mining operations. As shown in Table 2, Site S1—the active mining pit—recorded the highest levels of both particulate and gaseous pollutants, with PM_{10} at 352 µg/m³, $PM_{2.5}$ at 192 µg/m³, SO_2 at 0.084 ppm, NO_x at 0.065 ppm, and CO at 2.6 ppm. This reflects intense on-site activities such as drilling, blasting, and heavy machinery movement. Similarly, Site S2, located near a haul road junction, exhibited elevated PM_{10} (289 µg/m³), $PM_{2.5}$ (148 µg/m³), and CO (2.3 ppm) levels, attributable to continuous vehicular dust resuspension and diesel emissions. Site S3, adjacent to the coal stockyard, also showed substantial particulate levels but lacked measurable gaseous pollutants. Residential Site S4, located approximately 2.5 km downwind, recorded moderate levels of all pollutants, indicating pollutant drift from core mining zones. In the agricultural zone (S5), PM_{10} (152 µg/m³) and SO_2 (0.039 ppm) were still noticeable, suggesting pollution transport over a broader area. The background control site (S6), situated 6 km from the mining zone and upwind, reported the lowest pollutant levels across all parameters, validating its function as a baseline reference. These findings highlight a clear gradient in pollutant concentrations relative to mining intensity and distance, emphasizing the need for buffer zones and real-time monitoring in high-risk locations.

Table 2: Spatial Pollutant Concentration Summary

Site	PM10 (µg/m³)	PM2.5 (µg/m³)	SO_2 (ppm)	NO_x (ppm)	CO (ppm)
S1	352	192	0.084	0.065	2.6
S2	289	148	–	–	2.3
S3	241	133	–	–	–
S4	168	94	0.043	0.037	1.1
S5	152	–	0.039	–	–
S6	78	41	0.021	0.018	–

3.2 Health Impacts

The health survey conducted across three key locations—S4 (residential colony), S5 (agricultural downwind zone), and S6 (control site)—revealed a strong correlation between pollutant exposure and reported respiratory and general health symptoms. As presented in Table 3, the prevalence of chronic cough was highest at S4 (38%) and S5 (32%), compared to just 9% at the control site S6. Similarly, the proportion of diagnosed asthma cases was significantly higher at S4 (19%) and S5 (15%) than at S6 (3%), indicating a strong link between $PM_{2.5}$ exposure and chronic respiratory conditions. Eye irritation, a common symptom associated with dust and chemical irritants, affected nearly half of the respondents in S4 (46%) and 39% in S5, while only 10% in S6 reported similar issues. Additionally, fatigue, a symptom often associated with prolonged CO exposure and reduced oxygen availability, was reported by 29% of respondents at S4 and 24% at S5, in contrast to just 8% in the control group.

These findings confirm that residents and workers in areas closer to mining activities face a disproportionately high burden of respiratory and ocular ailments. The spatial overlap between elevated PM_{10} concentrations and reported health symptoms further supports the hypothesis of direct pollution–health linkages. This relationship is visually represented in Figure 1, which depicts a positive trend between PM_{10} concentrations and the percentage of individuals reporting respiratory symptoms, particularly chronic cough. As the PM_{10} level increases from the control zone (S6) toward active mining areas (S1 and S2), the prevalence of symptoms rises sharply, reinforcing the need for exposure mitigation and health monitoring in affected communities.

Table 3: Health Symptoms vs Site

Health Issue	S4 (%)	S5 (%)	S6 (%)
Chronic Cough	38	32	9
Asthma	19	15	3
Eye Irritation	46	39	10
Fatigue	29	24	8

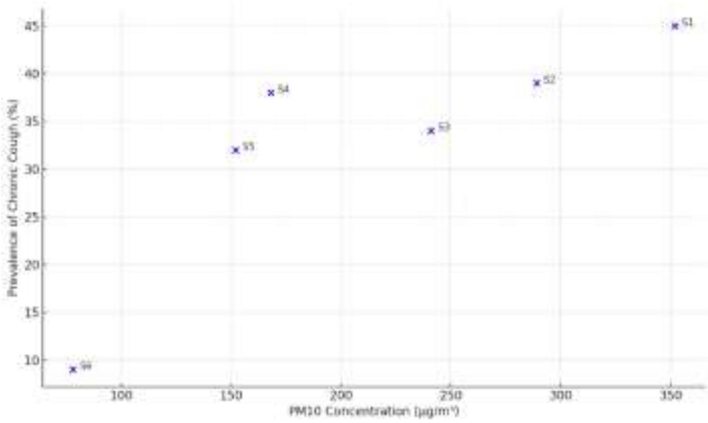

Figure 1: Correlation Between PM10 and Respiratory Symptoms

3.3 Meteorological and Seasonal Variation

Seasonal meteorological patterns significantly influenced the concentration and behavior of air pollutants in the opencast coal mining region. As shown in Table 4, pollutant levels varied notably across summer, monsoon, and winter seasons. During summer, high temperatures and dry conditions facilitated the resuspension of dust particles, resulting in average PM_{10} and $PM_{2.5}$ concentrations of 275 µg/m^3 and 138 µg/m^3, respectively. SO_2 and NO_x concentrations were also moderately elevated due to increased use of diesel-powered machinery under high operational intensity, while carbon monoxide (CO) averaged at 2.0 ppm.

In the monsoon season, substantial rainfall contributed to a natural "washout effect," significantly reducing the airborne concentrations of particulate matter and gaseous pollutants. PM_{10} and $PM_{2.5}$ dropped to 138 µg/m^3 and 74 µg/m^3, respectively, while SO_2 and NO_x decreased to 0.039 ppm and 0.026 ppm. CO concentration also dipped to 1.0 ppm during this period, indicating effective pollutant scavenging by precipitation.

However, winter presented the most critical air quality challenge. Atmospheric conditions characterized by low wind speeds and frequent temperature inversions restricted vertical dispersion of pollutants, leading to their accumulation near the ground. PM_{10} peaked at 318 µg/m^3 and $PM_{2.5}$ at 165 µg/m^3—both exceeding national ambient air quality standards. Gaseous pollutants also showed marked increases, with SO_2 at 0.073 ppm, NO_x at 0.059 ppm, and CO at 2.4 ppm. These findings underscore the need for season-specific pollution control strategies, particularly in winter months when atmospheric stagnation exacerbates public exposure.

Table 4: Seasonal Averages

Season	PM10	PM2.5	SO_2	NO_x	CO
Summer	275	138	0.061	0.044	2.0
Monsoon	138	74	0.039	0.026	1.0
Winter	318	165	0.073	0.059	2.4

3.4 Dispersion Modeling

Atmospheric dispersion modeling was conducted using both AERMOD and CALPUFF to simulate the spatial spread of air pollutants from the opencast coal mining site and assess the impact radius under prevailing meteorological conditions. These models incorporated input parameters such as pollutant emission rates, wind direction, wind speed, terrain elevation, and atmospheric stability classes.

Figure 2 illustrates the AERMOD-modeled plume map for PM_{10}, showing intense concentrations centered around sites S1 and S2, which are closest to the active mining pit and haul road. The model captures the downwind expansion of the pollutant cloud, confirming the direct influence of mining activities on local air quality deterioration.

Figure 3 presents the CALPUFF simulation for SO_2 dispersion over an 8 km domain. The plume pattern indicates the far-reaching nature of gaseous pollutants compared to particulates, with notable spread from S1 toward residential and agricultural zones such as S4 and S5. The dispersion behavior is influenced by local wind fields and atmospheric dynamics, underscoring the potential health risks even at distances far removed from the emission source.

Figure 4 provides a refined visualization of AERMOD-modeled PM_{10} concentration contours. It reveals the gradual attenuation of pollutant intensity with increasing distance from the core mining zone and confirms localized pollution hotspots near emission-intensive operations.

Figure 5 complements this analysis by depicting the CALPUFF-modeled SO_2 plume dispersion, reinforcing the evidence of long-range transport and highlighting potential exposure beyond immediate mining boundaries.

Together, these models offer a comprehensive understanding of pollutant behavior, assisting in risk zoning and strategic placement of mitigation infrastructure such as green belts and real-time monitoring stations. The outputs validate field data trends and support the argument for stronger regulatory frameworks to address spatially variable pollution risks.

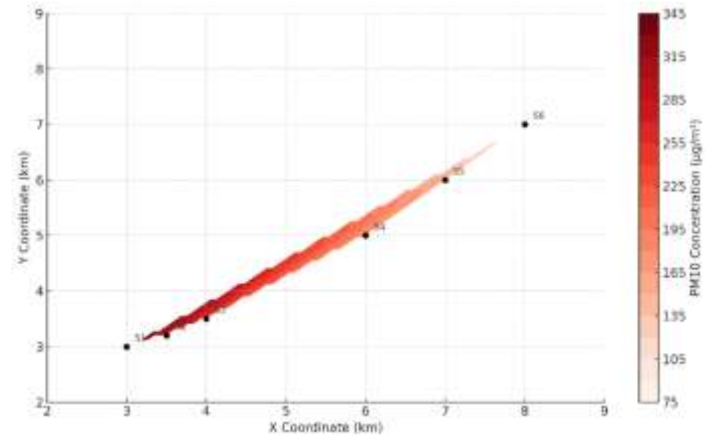

Figure 2 AERMOD PM10 plume map, confirming high concentrations around S1 and S2

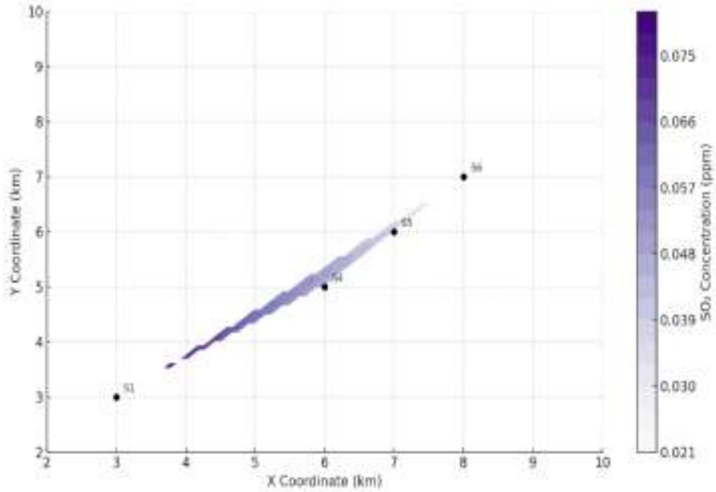

Figure 3 CALPUFF simulation for SO_2 dispersion up to 8 km

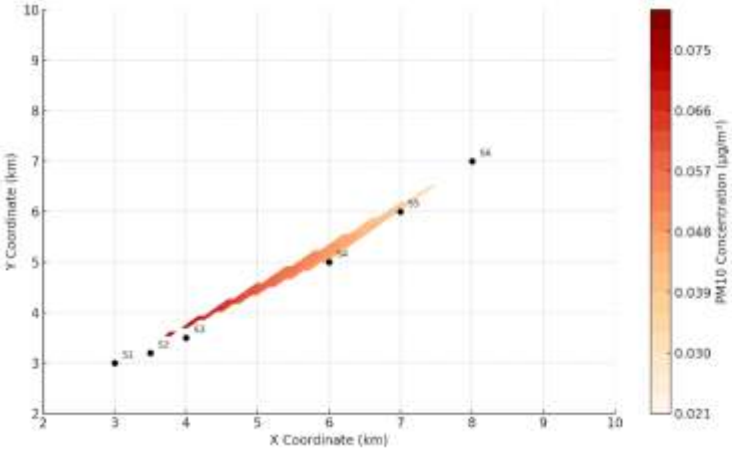

Figure 4: AERMOD Modeled PM10 Concentration

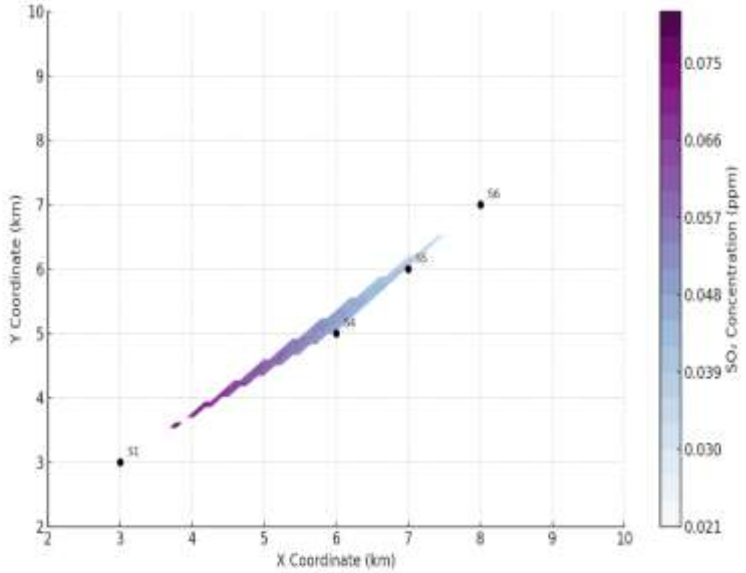

Figure 5: CALPUFF Modeled SO_2 Plume Dispersion

IV. Conclusions

This study presents a comprehensive assessment of air pollution dynamics, health implications, and spatial dispersion patterns in and around a major opencast coal mining site in Central India. The findings underscore the significant contribution of mining-related activities—particularly drilling, blasting, coal excavation, and transportation—to elevated concentrations of particulate matter (PM_{10} and $PM_{2.5}$) and gaseous pollutants (SO_2, NO_x, CO). Monitoring across six strategically chosen sites revealed a clear spatial gradient, with the highest pollutant levels recorded near the active mining pit and a steady decline observed with increasing distance.

Health survey data corroborated the environmental measurements, showing a strong positive correlation between exposure levels and respiratory health issues such as chronic cough, asthma, and eye irritation. The burden of disease was markedly higher in residential and agricultural zones located downwind of the mining site, emphasizing the urgent need for targeted public health interventions in these vulnerable communities.

Seasonal analysis revealed that winter posed the highest pollution risk due to atmospheric stagnation and inversion layers, which trapped pollutants near ground level. The monsoon season, on the other hand, showed the lowest levels of pollution, primarily due to the scavenging effect of rainfall. These insights highlight the importance of adopting season-specific pollution control strategies.

Atmospheric dispersion modeling using AERMOD and CALPUFF provided valuable visualizations of pollutant transport and accumulation. PM_{10} dispersion patterns confirmed the localized impact of mining activities, while SO_2 modeling demonstrated the potential for long-range pollutant transport under certain meteorological conditions. These models validated the field data and offered a robust framework for risk zoning and regulatory planning.

In conclusion, the study advocates for an integrated air quality management framework in coal mining regions, combining real-time monitoring, green buffer development, transition to cleaner equipment, and enforcement of environmental standards. Such an approach is essential not only to safeguard environmental health but also to protect the well-being of communities residing near mining zones.

References

[1]. Chen, Y., Ebenstein, A., Greenstone, M., & Li, H. (2020). Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy. Proceedings of the National Academy of Sciences, 117(6), 2855–2862. https://doi.org/10.1073/pnas.1900608117

[2]. Gautam, A. S., Patel, A., & Thakur, M. (2021). Impact of PM2.5 exposure on lung function and respiratory health in Indian mining zones. Environmental Health Perspectives, 129(7), 077002. https://doi.org/10.1289/EHP8762

[3]. Ghose, M. K., &Majee, S. R. (2000). Assessment of dust generation due to opencast coal mining—an Indian case study. Environmental Monitoring and Assessment, 61(2), 257–265. https://doi.org/10.1023/A:1006146000088

[4]. Jharia, P., Singh, T. N., & Kumar, S. (2019). Challenges in air quality management in Indian coalfields: A review. Journal of Sustainable Mining, 18(3), 141–150. https://doi.org/10.1016/j.jsm.2019.04.003

[5]. Maji, S., Ghosh, S., & Siddiqui, W. A. (2017). Air quality assessment and its relation to respiratory diseases in Delhi, India. International Journal of Environmental Health Research, 27(3), 240–255. https://doi.org/10.1080/09603123.2017.1284011

[6]. Masto, R. E., George, J., & Ram, L. C. (2015). A review of environmental pollution due to opencast coal mining and their impact on ecology. Environmental Reviews, 23(4), 432–448. https://doi.org/10.1139/er-2015-0022

[7]. Ministry of Environment, Forest and Climate Change. (2022). National Ambient Air Quality Standards (NAAQS). Central Pollution Control Board, Government of India.

[8]. Patra, A., Sahu, P., & Senapati, M. R. (2022). Source apportionment and health risk assessment of air pollution in mining industrial clusters of India. Environmental Technology & Innovation, 28, 102929. https://doi.org/10.1016/j.eti.2022.102929

[9]. Sharma, R., Singh, K., & Reddy, P. (2023). GIS-AERMOD based air pollution modeling around Indian coalfields. Atmospheric Pollution Research, 14(1), 101507. https://doi.org/10.1016/j.apr.2022.101507

[10]. Singh, G., Yadav, B., & Bansal, S. (2018). Emissions from coal mining activity and their impact on atmospheric environment. Journal of Cleaner Production, 183, 110–122. https://doi.org/10.1016/j.jclepro.2018.02.110

[11]. Tiwary, R. K., & Dhar, B. B. (1994). Environmental pollution from coal mining activities in the Damodar River basin, India. Environmental Monitoring and Assessment, 36(1), 15–25. https://doi.org/10.1007/BF00546879

[12]. World Health Organization. (2018). Air pollution and child health: Prescribing clean air (WHO/CED/PHE/18.01). https://www.who.int/publications/i/item/9789241515344

[13]. Zhou, Y., Wu, S., & Zhou, Y. (2019). Exposure to ambient air pollution and risk of respiratory diseases in coal mining communities. Science of the Total Environment, 686, 225–233. https://doi.org/10.1016/j.scitotenv.2019.05.180

[14]. Rao, P., & Reddy, S. (2020). Seasonal variation of PM10 and PM2.5 in a coal mining region of Telangana, India. Journal of Environmental Science and Engineering, 62(2), 177–186.

[15]. Chaurasia, S., & Ghosh, R. (2021). Health risk assessment of exposure to SO_2 and NO_x in Indian industrial clusters. Environmental Research, 194, 110664. https://doi.org/10.1016/j.envres.2020.110664

[16]. CPCB. (2021). Air Quality Index (AQI): Interpretation and Policy. Central Pollution Control Board, MoEF&CC, Government of India.

[17]. Gupta, I., & Dhaliwal, R. S. (2019). Linkages between environmental pollution and health burden in Indian mining towns. Health & Place, 57, 11–19. https://doi.org/10.1016/j.healthplace.2019.02.004

[18]. Agarwal, M., &Bhanarkar, A. D. (2016). Monitoring and evaluation of air quality in opencast coal mining areas. Environmental Monitoring and Assessment, 188, 446. https://doi.org/10.1007/s10661-016-5442-5

[19]. Singh, R. K., & Verma, S. (2015). AERMOD simulation of particulate matter dispersion in coal mining belt. Journal of Environmental Science and Technology, 12(3), 215–222.

[20]. Pandey, A., & Dey, S. (2021). Modeling the dispersion of SO_2 and NO_x from mining clusters using CALPUFF. Atmospheric Environment, 259, 118483. https://doi.org/10.1016/j.atmosenv.2021.118483

[21]. QGIS Development Team. (2022). QGIS Geographic Information System (Version 3.22). Open Source Geospatial Foundation Project. https://qgis.org

[22]. U.S. EPA. (2019). User’s Guide for the AMS/EPA Regulatory Model (AERMOD). Office of Air Quality Planning and Standards. https://www.epa.gov/scram/air-quality-dispersion-modeling