

Assessment of Environmental Impact of Iron Ore Mining on the Air Quality in Koira Mining Area, India

Adolphus M. G. D. Gleekia¹, Himanshu Bhushan Sahu²

¹Department of Mining Engineering, University of Liberia, Monrovia, Liberia

²Department of Mining Engineering, National Institute of Technology (NIT), Rourkela, India

Email: gleekaiad@ul.edu.lr

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Abstract

Mining for iron ore produces large amounts of particulate matter (PM) and related gaseous emissions, making it a major stationary source of air pollution. In the mining zones of Barsua-Tensa and Koira in Odisha, India, this study evaluated the ambient levels of PM₁₀ and PM_{2.5} as well as their chemical properties. Using respirable dust samplers (Envirotech APM 460 NL) and fine particle samplers (Envirotech APM 550) in accordance with IS:5182 standards, air quality monitoring was carried out at 10 sampling points throughout mining townships. Mass concentrations were calculated by gravimetric analysis, and microwave acid digestion (US EPA Method 3052) and ICP-MS analysis were used to characterize trace metals in a subset of PM_{2.5} samples. The findings showed that PM₁₀ concentrations were higher than the National Ambient Air Quality Standards (NAAQS) at every test site, while PM_{2.5} levels were higher than allowable limits at a number of sites, especially in Koira Township. PM₁₀ was rated as “Moderate” to “Extremely Hazardous” by the Air Quality Index (AQI), while PM_{2.5} was rated as “Unhealthy for Sensitive Groups” to “Unhealthy”. Increased concentrations were closely linked to heavy haul-road traffic, which involved over 1500 dumpers moving iron ore concentrates at night. Significant concentrations of key elements (Na, K, Ca, Mg, Al, Fe) and trace metals (Ba, Zn, Mn, Cr, Ni, Pb, Hg, Cd, and As) were found in mineralogical examination, suggesting possible toxicological hazards. The results show that the ambient air quality in the mining corridors under study has significantly deteriorated, with Koira Township having the highest pollution burden. There are serious dangers to community and occupational health from prolonged exposure to increased respirable particles and metal-enriched dust, including systemic poisoning and respiratory morbidity. Coordinated emission control measures that target haul-road dust, improved traffic manage-

ment, and cooperative regulatory oversight are necessary for effective mitigation in order to lower PM levels below tolerable bounds.

Keywords

Iron Ore Mining, Particulate Matter (PM₁₀ and PM_{2.5}), Air Quality Index (AQI), Trace Metal Contamination, Haul-Road Dust Emissions, Ambient Air Quality Monitoring, Occupational Health Risk, National Ambient Air Quality Standards (NAAQS)

1. Introduction

The iron ore mining sector is widely acknowledged as a major contributor to air pollution, especially in areas where large-scale extraction and processing activities take place. Mining operations, such as drilling, blasting, excavation, loading, and transportation, emit high levels of particulate matter (PM) and harmful gases like sulfur oxides (SO_x), nitrogen oxides (NO_x), carbon dioxide (CO₂), and carbon monoxide (CO) [1] [2]. Iron ore mines are stationary sources of air pollution, constantly producing fugitive dust and gaseous pollutants. These emissions cause the deposition of wet and dry particulate matter across mining areas' ecosystems, affecting soil chemistry, water quality, and vegetation health [2].

Particulate matter is classified as coarse or fine, with each having its own environmental and biological influence. PM can cause chemical and physical harm to plants and animals, with vegetation being more vulnerable due to its immobility and persistent exposure to atmospheric stressors [3] [4]. PM deposition on plant surfaces disrupts critical physiological processes by blocking light required for photosynthesis, clogging stomatal apertures, raising leaf surface temperature, and altering pigment composition and mineral intake [5]. These disturbances impair plant metabolism, slow growth rates, and lower sensitivity to other environmental stressors, ultimately harming biodiversity and ecosystem stability.

Particulate matter is a broad term that describes complex combinations of airborne particles suspended in respirable air. These particles vary in size, composition, and origin, and are produced by both natural processes (e.g., volcanic activity, wind erosion) and human activities (e.g., mining, industrial combustion, vehicle emissions). PM is regarded as one of the most pervasive occupational and environmental risks, classified according to its effects on human health, ecosystems, and atmospheric quality [6]-[8]. Its environmental consequences are mostly due to airborne and non-airborne PM generated by mechanical processes that break solid materials into fine particles. These particles cause long-term ecological imbalance, deteriorate air quality, and settle on terrestrial and aquatic ecosystems after they are released [9] [10].

Understanding the dynamics of particulate matter creation and its ecological effects is crucial given the scope of iron ore mining and the emissions that go along

with it. This information serves as the basis for developing efficient mitigation plans, enhancing environmental monitoring, and guiding sustainable mining methods that strike a balance between ecological preservation and economic growth. Once released, these particles settle on terrestrial and aquatic ecosystems, degrade air quality, and contribute to long-term ecological imbalance [9] [10].

In iron ore mining locations, there is still little integration of site-specific air quality measurements with in-depth mineralogical characterisation and localized exposure assessment, despite the fact that particle emissions from mining activities are well documented. Particularly, in highly active mining routes like Barsua-Tensa-Koira, few investigations concurrently assess PM₁₀ and PM_{2.5} concentrations, their chemical makeup, and related health hazards.

Thus, the current study's objectives are to: 1) measure ambient concentrations of PM₁₀ and PM_{2.5} in a few chosen mining townships; 2) calculate the Air Quality Index (AQI) and its health implications; 3) describe the mineralogical and trace metal composition of particulate matter; and 4) identify the main emission sources affecting the study area's air quality. The findings are meant to guide site-specific mitigation methods and provide a more comprehensive understanding of particle pollution dynamics in comparable iron ore mining environments. The scope of inference is limited to the chosen mining clusters in Odisha.

2. Impacts of Particulate Matter Generation Due to Iron Ore Mining on Health and Environment

It is widely known that the contamination of air quality can trigger various environmental issues. The iron mineral extractive industry is one of the fundamental sources of air contamination, since its activities produce notable levels of PM and an extensive volume of toxic gases, for example, sulfur dioxide (SO_x), oxides of nitrogen (NO_x), carbon monoxide (CO), carbon dioxide (CO₂), etc. [11] [12]. As a stationary source of contamination, iron mining activities can cause and deliver widespread amounts of PM and toxic gases, which may increase ground level concentrations of wet as well as dry PM on flora and fauna in and around the mine vicinity [4] [11] [13].

PM of coarse and fine sizes has various harmful effects on plants and animals, some of which include chemical and physical injuries. Plants, in particular, are susceptible to suffering from PM largely due to their inability to escape from stress-causing agents in the environment [14] [15]. PM can affect plant metabolism depending on its size ranges—blocking light needed for photosynthesis, hindering stomatal apertures in plants, increasing leaf temperature, and altering leaf pigment and mineral content [16] [17].

PM is among the most rampant occupational hazards and may be classified according to their occupational, environmental, and physiological health effects. Their environmental impact is basically due to airborne and non-airborne PMs that are mostly generated through mechanical processes that disintegrate solid substances into fines [18] [19].

The size of PM fluctuates and determines the site of deposition in the respiratory tract of humans. Thus, PM₁₀ are usually deposited in the upper segment of the respiratory tract, while PM_{2.5} and ultrafine particles are deposited in the alveoli of the lung [7] [20]. Hence, no single section has been perceived that could clarify by far most of the PM impacts. The health effect of PM is mostly reliant on the size and surface of individual particles, the concentration being exposed to, and the chemical constituents. With regard to their composition, PM are fundamentally made out of metals, composites of organic matters, particles, organic materials, reactive exhaust, and particulate carbon core [7] [21] [22].

The exposure of humans to PM in higher concentrations may provoke respiratory difficulties in humans and affect the body in assorted ways, which may induce harmful impacts following contact with the skin or eye, ingestion, and inhalation due to their individual physical and chemical properties. Long-term exposure to PM above permissible limit values may give rise to a variety of harmful diseases in mineworkers and residents of the mine's lease area and adjoining regions [23] [24]. The well-known of these are pneumoconiosis and silicosis, asbestosis, coal workers pneumoconiosis (CWP), malignancy; lung cancer (due to quartz and cristobalite silica, etc.); injury to the nose, throat, and eyes; damage to the skin such as dermatitis or skin cancer; skin retention and systematic harming; irritation of the gastrointestinal tract through ingestion; ischaemic heart maladies; irritation and incendiary wounds to the lung; allergic responses; affect developing embryo amid pregnancy [8] [25].

PM can influence safety in the workplace, prompting diminished visibility, and the annoyance fixations under such conditions ought not to be taken too lightly [26] [27].

Sources and Their Impact

There are two sources of PM emission in mines, viz. Primary and Secondary. The primary sources include: 1) drilling and blasting, where air blast and blast intensity are the main mechanisms of emission; 2) crushing sites and associated processes, where impacts, dropping of materials from a specified altitude, and abrasion are the major mechanisms of emission [28] [29]. The secondary sources include: 1) conveying sites, where dropping of materials from a specified altitude is the mechanism of emission [30] [31]; 2) haulage roads, where raise, exhaust, tyres, and cooling fans of dumpers are the main mechanisms of emission [30] [32] [33]; and 3) stock piles, where the mechanisms of emission are caused by wind speed and wind blow.

3. Materials and Methods

3.1. Study Area

In an attempt to assess the environmental impact of iron ore mining, two different iron ore mining regions were selected. The first one is the Barsua-Tensa Area (BTA), and the second is Koira Township, both of which are situated in the

Keonjhar and Sundergarh Districts of Odisha, India.

The study area contains 73 mines in total. Of these, 23 were active during the study period mining iron and manganese ores on a large scale. Iron ore being mined in the regions serves as a major source of raw materials for steel plants within and outside of Odisha State. Some of these steel plants include Rourkela Steel Plant (RSP), Tata Steel Ltd (TSL), Jindal Steel and Power Ltd (JSPL), etc. The study zone can be found within the space of latitude $21^{\circ}52'48''$ and $21^{\circ}53'58''\text{N}$ and longitude $85^{\circ}08'37''$ and $85^{\circ}17'22''\text{E}$. The map of the study area is presented in **Figure 1**.

To increase reproducibility and openness, the sampling framework has been made clearer. Due to low moisture levels, particulate emissions from mining and haul-road operations are usually at their highest during the dry season (pre-monsoon period), when ambient air monitoring was carried out. Each of the ten monitoring stations was sampled several times throughout the course of a continuous 15-day period. Using established procedures, paired PM_{10} and $\text{PM}_{2.5}$ samples were obtained concurrently at each site for eight hours during each sampling event. As a result, each site had several observations, which increased the dataset's dependability and made it possible to evaluate short-term variability.



Figure 1. Map of the study area showing all sampling stations (D1 - D10).

The ten sampling locations were chosen and dispersed geographically according to the mining corridor's population exposure, land-use features, and emission intensity. Due to its high density of operating mines, processing facilities, and significant haul-road junctions, Tensa represents the operational center of the mining activity and was given five sampling locations. Because Koira is a major residential and transportation hub with substantial vehicle traffic and human exposure, it was given four sites. In order to depict background and transitional conditions, one site was used to represent Barsua, which has comparatively less mining activity within the township boundaries and functions more as a peripheral

zone. Thus, a gradient of mining intensity and exposure risk along the corridor is reflected in the combined distribution of 1 (Barsua), 5 (Tensa), and 4 (Koirā), guaranteeing that the sampling strategy appropriately represents both source-dominated and receptor-sensitive situations. Along the mining corridor, this distribution as a whole offers a fair depiction of upstream, midstream, and downstream impacts.

3.2. Sample Collection

Air Quality Monitoring (AQM) was carried out in the mining townships of Barsua, Tensa, and Koirā, inhabited by miners and locals. From the studies, PM₁₀ and PM_{2.5} were sampled at ten different locations, one set (PM₁₀ & PM_{2.5}) from Barsua, five sets from Tensa, and four sets from Koirā townships with the help of Respirable Dust Samplers, Model: Envirotech APM 460 NL, and Fine Particulate Samplers (Model: Envirotech APM 550). At each sampling station, PM₁₀ and PM_{2.5} were gathered simultaneously, sampling 2 locations at a time using 4 samplers to optimize the sampling process (two PM₁₀ and two PM_{2.5} samplers). Respirable Dust Samplers (Model: Envirotech APM 460 NL) were used to collect PM₁₀ samples, while Fine Particulate Samplers (Model: Envirotech APM 550) were used to collect PM_{2.5} samples. PM_{2.5} samplers were manually operated (non-programmable), while the PM₁₀ samplers were operated by means of programming on an 8-hourly basis. The maximum sampling time for both samplers (PM₁₀ and PM_{2.5}), as per manufacturer prescription, is 24 hours, while the minimum sampling time is 8 hrs. Whatman GFA 8" × 10" filter paper was used for gathering PM₁₀ while the Teflon filter papers were used to gather PM_{2.5} samples.

The National Ambient Air Quality Standards (NAAQS) particulate matter limitations were directly compared to the 8-hour average PM concentrations recorded at each location. Rather than offering a complete compliance judgment, these comparisons are clearly given as screening-level assessments meant to show whether detected concentrations approach or surpass regulatory criteria.

The U.S. EPA's AirNow calculator was utilized to convert measured values into Air Quality Index (AQI) categories. Because it offers a clear, well-known conversion framework and enables uniform interpretation of pollutant concentrations in terms of public health importance, this tool was chosen. The AirNow/US EPA calculator uses a standardized breakpoint approach that is generally equivalent to other AQI frameworks, which justifies its use as a screening tool even though the study region is in India. One AQI framework (AirNow/US EPA) has been used consistently throughout the article to prevent confusion, and this justification is now made clear.

PM₁₀ filters were used in the field to collect all suspended particles for particulate sampling. A size-selective extraction procedure was then used in the lab to separate the fine fraction (PM_{2.5}) from these filters. In order to ensure that the data represent the subset most pertinent to human exposure and atmospheric transport, this PM_{2.5} fraction was further subjected to chemical digestion and analysis.

Six sites (D4, D5, D7, D8, D9, and D10) were selected for chemical analysis out of the ten monitoring locations due to their high PM concentrations, AQI classifications (which range from “Unhealthy” to “Extremely Hazardous”), and proximity to sensitive receptors like residential areas, schools, transportation hubs, and medical facilities. This targeted selection approach was used to ensure spatial representation throughout the most affected areas of the mining corridor while concentrating on high-exposure zones where possible health hazards are highest.

The PM₁₀ sampler is a rectangular, wheeled device with an internal pump mechanism and an inlet pipe, as seen in **Figure 2(a)**. It gathers ambient air’s respirable particulate matter ($\leq 10 \mu\text{m}$), mostly coarse dust produced by environmental and mechanical processes. This study made use of it. The cyclone separation concept utilized in PM₁₀ measurements was also applied in **Figure 2(b)**. The cyclone assembly uses centrifugal force to remove bigger particles when ambient air enters through the inlet. While finer particles go via a filter and gasket before the cleaned air exits to the suction mechanism, these particles are gathered in the sample bottle. The diagram illustrates a two-step procedure that ensures efficient collection of respirable dust: mechanical separation and filtration.

Furthermore, the PM_{2.5} sampler (**Figure 2(c)**) is a rectangular apparatus with an intake assembly intended to specifically collect tiny particulate matter ($\leq 2.5 \mu\text{m}$), which presents serious health risks because of deep lung penetration. Its front panel shows an oilless vacuum pump for continuous air intake and filtering, while its enclosure displays tubing, filters, and a chamber. This device, which focuses on health-relevant tiny particles, is frequently used in pollution studies and air quality monitoring.

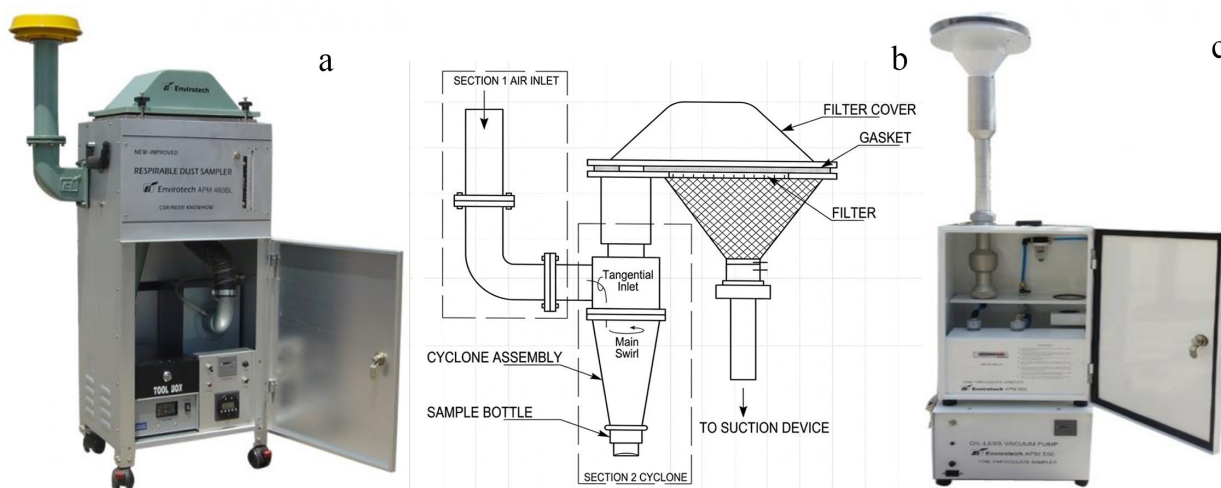


Figure 2. (a) & (b): PM₁₀ sampler and schematic diagram; (c): PM_{2.5} sampler.

Standard procedures (IS: 5182, Part 4, 6 & 23) were adopted for the studies. Prior to field sampling, the filter papers were equilibrated by exposing them in an airtight desiccator containing active desiccant, temperature controlled ($15^{\circ}\text{C} - 27^{\circ}\text{C}$) and relative humidity of 0% - 50% for 24 hrs. After equilibration, the initial weight (W_i)

of all filters (Whatman & Teflon) was recorded using an analytical balance and given unique identification numbers, retained in filter holders, and properly sealed to prevent contact with moisture. All samples were collected for 8 hrs at a constant air flow rate in an interval of 1.0 to 1.2 m³/min, respectively. After sampling, the samples were carefully placed in filter holders, sealed tightly to prevent the escape of particles, and transported to the Environmental Engineering Laboratory of the Mining Engineering Department, National Institute of Technology, Rourkela (NITR), for gravimetric analysis. After the filter papers were gravimetrically analysed, they were preserved for mineralogical characterization of PM sampled.

3.2.1. Procedures for Quality Assurance and Control (QA/QC)

To guarantee data accuracy and dependability, quality assurance and control (QA/QC) protocols were used for both ICP-MS analysis and particulate matter (PM) sampling. In order to preserve flow rate accuracy within $\pm 5\%$ of the intended range for PM measurements, all samplers (Envirotech APM 460 NL and APM 550) were calibrated using a standard flow calibrator both before and throughout the sampling session. Leak checks were performed both before and after sampling, and flow rates were noted in order to calculate average volumetric flow. In order to account for background contamination, field blanks and laboratory blanks—unused filter papers that underwent the same handling and conditioning—were examined, and blank corrections were made as needed. To evaluate measurement precision, duplicate (replicate) sampling was conducted at certain locations, with acceptable variability kept under $\pm 10\%$. Gravimetric measurements were carried out using a calibrated analytical balance with the proper sensitivity, and filters were equilibrated under regulated temperature and humidity conditions both before and after sampling to reduce weighing errors.

Reagent blanks, method blanks, and certified reference materials (CRMs) were used in QA/QC procedures for ICP-MS analysis in order to confirm analytical accuracy. Multi-element standard solutions with appropriate correlation coefficients ($R^2 \geq 0.999$) were used to create calibration curves. Drift adjustments were made as needed, and the calibration of the instrument was regularly confirmed using calibration check standards. To guarantee analytical precision, duplicate analyses of digested samples were carried out, usually within $\pm 5\%$ - 10% relative standard deviation. Only concentrations above detection limits were reported, and method detection limits (MDLs) for trace elements were established using standard techniques (e.g., three times the standard deviation of blanks). Consistent replication measurements, acceptable recovery rates for CRMs (usually 85% - 115%), and appropriate blank values were among the requirements for data acceptance. To preserve overall data integrity, any data that did not fit these requirements were either reanalyzed or eliminated.

3.2.2. Basis of Trace-Metal Concentration Reporting

The digestate concentrations (mg/L) obtained from the microwave-assisted acid digestion of PM₁₀-loaded filter sheets and dilution of the extracts to a fixed volume

(100 mL) before ICP-MS analysis are used to express the trace-metal values reported in this study. Therefore, rather than the direct mass of metals per unit volume of ambient air, the given values represent the concentration of each element in the examined solution.

Therefore, these values should not be construed as ambient atmospheric metal concentrations because they are not air-volume-normalized (e.g., $\mu\text{g}/\text{m}^3$). The given trace-metal values are not standardized to the observed air volume; rather, they are raw digestion outputs (amount of metal found in the filter extract or per filter). Results must be given as air-volume-normalized values ($\mu\text{g}/\text{m}^3$), which take into consideration the volume of air collected and enable comparison with standards, in order to represent ambient atmospheric concentrations. Digestate or per-filter values should be regarded as intermediate analytical results rather than exposure-relevant measures, since they merely characterize the chemical content of the sample. To put it briefly, ambient air concentrations should be measured in $\mu\text{g}/\text{m}^3$; other bases cannot be easily compared to air quality standards. Rather, they show the distribution and relative abundance of constituents linked to particulate matter collected on each filter, allowing for cross-site comparison and the identification of possible emission sources. All values are air-volume-normalized concentrations ($\mu\text{g}/\text{m}^3$), which are determined by dividing the total volume of air sampled through the filter by the mass of each metal measured in the digestate. In order to establish comparability with ambient air quality standards and to enable meaningful interpretation in terms of human exposure, the mass per filter obtained from the digestion step was adjusted to the observed air volume.

4. Results

4.1. Determination of Concentration (PM_{10} & $\text{PM}_{2.5}$)

After 8 hrs of sampling, the filter papers from both samplers were carefully taken out and placed in their respective holders, numbered, and sealed to prevent the escape of particles. Before gravimetric investigation, the filters were placed in a desiccator (DC) for 24 hours (equilibration) to remove absorbed moisture during sampling, after which the final weight of each filter was determined using an Analytical Balance and recorded as W_f . The appearance of the filter papers before and after 8 hrs of sampling can be seen in [Figure 3](#), and it presents the equilibration of all filter papers after field sampling by means of the desiccator.

Calculations:

The volume flow rate of air (V) for both samplers can be computed as:

$$V = QT \quad (4.1)$$

where,

V = Volume of air flow sampled in m^3 ,

Q = Average flow rate of air in m^3/min , and

T = Total time of sampling in min.

The total concentration of $PM_{2.5}$ and PM_{10} in ambient air samples was calculated by the given equation:

$$PM_{10} \text{ or } PM_{2.5} = \left[(W_f - W_i) \times (10)^6 \right] / V \quad (4.2)$$

where,

$PM_{2.5}$ = Mass concentration of $PM_{2.5}$ in $\mu\text{g}/\text{m}^3$,

PM_{10} = Mass concentration of PM_{10} in $\mu\text{g}/\text{m}^3$,

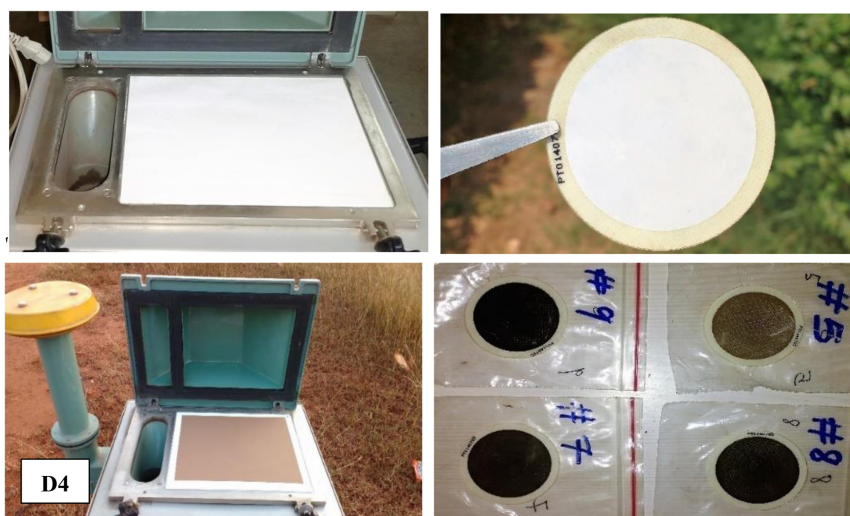
W_i = Initial weight of filter paper in g,

W_f = Final wt. of filter paper in g,

V = Volume of air flow sampled in m^3 , and

10^6 = Conversion of g to μg .

The concentration of PM_{10} and $PM_{2.5}$ for all the sampling points was determined following the above-mentioned procedures and is presented in **Table 1**, while the filter papers' appearance prior to and before the sampling of airborne particulates (PM_{10} & $PM_{2.5}$) at a few sampling stations is shown in **Figure 3**, respectively. The results of PM concentrations found from each of the 10 sampling stations, corresponding air quality index (AQI) values, and associated health concerns are presented in **Table 1**.



(Top to bottom left—Whatman GFA 8'' × 10'' filters, for PM_{10}); Top to bottom, right—Teflon filters for $PM_{2.5}$. Labels on each filter denote the sampling station at which the sample was gathered.

Figure 3. Filter papers' appearance prior to and after 8 hrs of sampling.

4.2. PM Characterization

In order to assess the potential health impacts of particulate matter, the filter papers (PM_{10}) were subjected to mineral characterization. Prior to trace element analysis, each filter paper was acid digested using a microwave digestion procedure (US EPA Method 3052). During digestion, each filter paper was cut using scissors and placed in an acid-washed (10% HNO_3) microwave bottle according

to their id. Nitric acid (HNO₃) and hydrochloric acid (HCl) were added to each sample in each vessel and sealed air-tight, in corresponding volumes of 9 ± 1 ml and 4 ± 1 ml, respectively. The vessels were then placed in the microwave digestion system and allowed to stay for 15 min at 180 °C ± 5 °C.

Table 1. Concentration found for PM (PM₁₀ and PM_{2.5}) after 8 hours of sampling.

Location	Code	PM ₁₀ (µg/m ³)	PM ₁₀ (AQI)	Health Concern	PM _{2.5} (µg/m ³)	PM _{2.5} (AQI)	Health Concern
Guest House, Barsua	D1	110.73	78	Moderate	40.54	113	Unhealthy for sensitive groups
Guest House, Tensa	D2	110.15	78	Moderate	50.19	137	Unhealthy for sensitive groups
Club House, Tensa	D3	162.89	104	Unhealthy for sensitive groups	36.99	176	Unhealthy
Koira's Collage	D4	270.34	158	Unhealthy	55.22	150	Unhealthy for sensitive groups
Koira's Bus Station	D5	844	>500	Extremely Hazardous	148.68	199	Unhealthy
Koira's Electrical Station	D6	436.52	315	Hazardous	88.61	168	Unhealthy
Community Health Center, Koira	D7	595.66	491	Hazardous	99.63	174	Unhealthy
A_59 SAIL Quarter, Tensa	D8	1046.96	>500	Extremely Hazardous	85.68	167	Unhealthy
Zero Point, Tensa	D9	369.69	221	Very Unhealthy	139.59	194	Unhealthy
Tensa Basti Primary School, Tensa	D10	927.35	>500	Extremely Hazardous	49.14	134	Unhealthy for sensitive groups
NAAQS		100	0 - 500		60	0 - 500	

Table 2. Chemical composition of particulate matter (PM).

Parameter Conc (mg/L)	Sampling Stations					
	D4	D5	D7	D8	D9	D10
Na	79.42	79.42	69.16	72.05	79.42	79.42
Mg	7.17	11.56	6.81	12.36	10.22	18.46
Al	102.11	109.46	75.14	93.68	109.23	109.77
K	89.12	88.12	76.20	76.13	89.12	88.65
Ca	52.66	62.55	43.11	38.95	51.29	44.42
Se	0.004	0.0104	0.0097	0.0101	0.0056	0.013
Total Cr	0.154	0.231	0.215	0.225	0.187	0.278
Mn	0.347	2.16	1.82	1.01	0.522	0.960
Total Fe	26.79	140.79	92.08	84.88	47.42	103.05
Co	0.0044	0.0143	0.0123	0.0130	0.0060	0.0152
Ni	0.1229	0.1163	0.0802	0.1333	0.1422	0.1675

Continued

Cu	0.0322	0.0671	0.0527	0.0578	0.0411	0.0891
Zn	74.25	60.70	67.47	56.22	69.29	61.83
As	0.0189	0.0264	0.0200	0.0196	0.0218	0.0183
Cd	0.0023	0.0023	0.0023	0.0011	0.0014	0.0014
Ba	138.70	105.73	110.88	100.84	134.00	107.79
Total Hg	0.0141	0.0124	0.0212	0.0120	0.0117	0.0190
Pb	0.0631	0.0693	0.0546	0.0579	0.0620	0.0721

The digested samples were filtered using Whatman filter 42 and the filtrates were diluted to 100 ml in a volumetric flask of 100 ml capacity and finally placed in a refrigerator at 4 °C for analysis. The six filtrates of the six microwave-digested filter papers were analysed using ICPMS, LSX-213. The filter papers digested were D4, D5, D7, D8, D9, & D10. The analytical results of trace elements found in the PM sampled are presented in **Table 2**.

The given trace-metal results should not be construed as ambient atmospheric concentrations ($\mu\text{g}/\text{m}^3$) because they represent digestate concentrations (mass per filter) and have not been adjusted to the observed air volume.

5. Discussion

5.1. Air Quality

The air we breathe is a mixture of gases with some measure of solid and liquid particles. Air contamination initiates in ambient air when substances are present in levels greater than their standard surrounding levels to produce quantifiable effects on humans, fauna, vegetation, resources, et cetera. Air contamination has been a widely recognized issue, and it is currently a significant environmental problem worldwide. In India, air quality pollution has become an important topic of controversy at all levels due to increased anthropogenic activities, especially the burning of coal, natural gas, fossil fuels, industrial activities, mining, and related activities, etc. These activities release a wide range of air pollutants, viz. CO, NO_x, VOCs, PM, and SO₂, etc. [34]. Mining operations create significant amounts of airborne respirable particulate matter because of the nature of operations, which causes pulmonary diseases in miners. The increasing trend of opencast mining to meet the ever-growing demands of the public leads to the release of a tremendous amount of dust [35] [36]. These airborne dust particles or PM, normally below 100 microns in size, are natural nuisances and the main cause of health hazards. The systematic results of PM₁₀, PM_{2.5} along with their standards have been presented in **Figure 4**.

It could be seen that PM_{2.5} levels of samples D1 - D4 and D10 were below the Central Pollution Control Board Standards of 60 $\mu\text{g}/\text{m}^3$. In any case, PM_{2.5} levels for D5 - D9 were observed to be far above the CPCB standard, with D5 having the highest estimation of 148.68 $\mu\text{g}/\text{m}^3$. The PM₁₀ concentration at all stations sam-

pled was above the acceptable limits of the National Ambient Air Quality Standard (NAAQS) of CPCB.

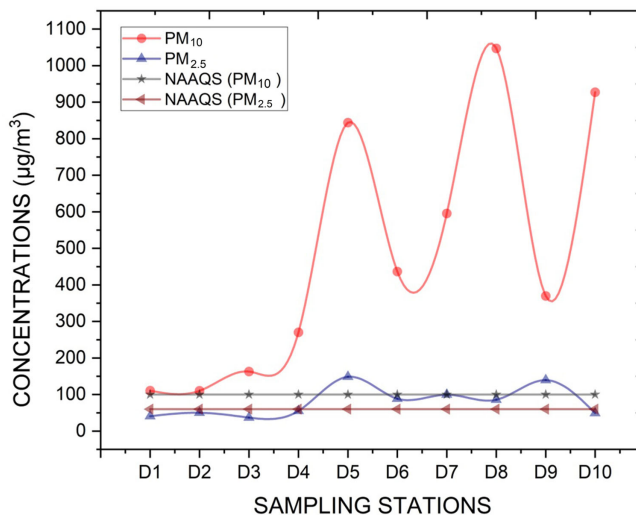


Figure 4. Graphical display of PM_{2.5} (left) and PM₁₀ (right) vs. NAAQS values.

The main sources of air pollution (PM₁₀ and PM_{2.5}) generation in the study area, as per field observation for 15 days in the study area coupled with sampling results, are haul roads. It was observed that over 1500 dumpers from more than 20 active iron and manganese mines transport run of mines and concentrates along the Koira-Tensa and Tensa-Barsua road networks on a 24-hourly basis. It is commendable to note that these pollutants (PM₁₀ & PM_{2.5}) are mostly engendered from 6:00 pm to 6:00 am. During these hours, the Tensa-Barsua and Tensa-Koira roads, as well as Koira Township, get heavily trafficked with dumpers loaded with concentrates and run of mines from all locations. Figure 5 presents dumpers’ traffic along the Tensa road network during loading.



Figure 5. Queuing of dumpers during loading operations in Tensa.

5.2. Mineralogical Characterization

Chemical analysis of 6 out of 10 filter papers investigated from delicate regions such as the health centre (D7), school zones (D4 & D10), bus station (D5), and inhabited areas (D8 & D9) displayed elevated levels in descending order as Ba, Al, Fe, Zn, Mn, Cr, Ni, Se, Co, As, Cd, Hg, and Pb. The cations were among the predominant constituents in descending order as K, Na, Ca, and Mg. Ni. Considering

the constituents of airborne particulates sampled, miners and inhabitants of the study area are at risk of suffering from respiratory health hazards or diseases.

The first figure (**Figure 6(a)**) demonstrates that Fe is the predominant element, with concentrations reaching a strong peak at station D5 (~160 mg/L). Na, Al, and K, on the other hand, show moderate but variable values throughout the sampling locations. Mg and Mn, on the other hand, are continuously low. With Fe dominance closely associated with iron-bearing geology and mining activity in the corridor, this variability points to limited mineralogical inputs.

The second figure (**Figure 6(b)**), peaks at station D10 (~0.32 mg/L), showing Cr as the element with the highest concentration. While As is generally low, below 0.1 mg/L, Ni exhibits substantial, varied amounts among the stations. While Ni and As are only present at negligible levels, the increased Cr levels at D10 indicate lithological enrichment or localized contamination.

The two locations differ significantly, according to the mineralogical characterization. Strong Fe dominance is seen in Tensa stations (D4 - D7), which is compatible with iron-rich geology. Koira stations (D8 - D10), on the other hand, have distinct Cr enrichment, especially at D10, suggesting distinct mineralogical origins. The impact of the mining corridor and the possibility of airborne particulate contamination are highlighted by elevated Fe and Cr values. Because of their possible effects on health, trace metals like Ni, As, and Mn are nevertheless important for toxicological evaluation even though their concentrations are still low.

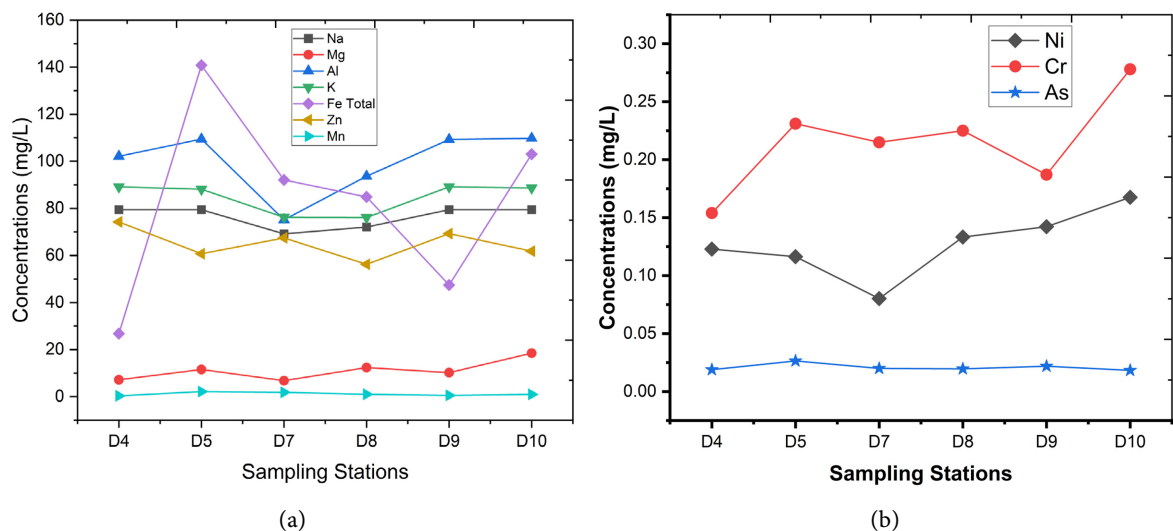


Figure 6. (a) & (b): Mineralogical characterization plot of PM vs. sampling stations in Tensa and Koira.

5.3. Quality Index (AQI)

The AQI is a guide developed by the USEPA for reporting daily air quality in an area. It tells one how clean or unhealthy the ambient air is, and what associated health effects might be a concern as the index value increases. The AQI focuses on health effects a person may experience within a few hours or days after exposure (breathing) to unhealthy air. The AQI is normally calculated for four major air

pollutants that are regulated by the Clean Air Act in the United States of America (USA) viz. particle pollution, ground-level ozone, sulfur dioxide, and carbon monoxide. Thus, to protect public health, the EPA has established National Air Quality Standards (NAQS) for each pollutant mentioned above. In this research, AQI has been determined for airborne particulates (particle pollution) only.

The AQI is a measurement that runs from 0 to 500. The higher the AQI value, the greater the concentration of air pollution and health concern in the area. For instance, an AQI value of 50 signifies good air quality with minimal or no potential to negatively impact public health, while a value of 300 means the air quality is hazardous, and that any exposure may result in serious health effects. An AQI value of 100 normally parallels the national air quality standard for the pollutant, which is the concentration set by the EPA to protect public health. Therefore, AQI values at 100 or below are generally accepted to be satisfactory. When AQI values exceed 100, the air quality is considered to be unhealthy, initially for certain sensitive groups of people, then for everyone as AQI values increase.

The purpose of the AQI is to help people understand what the local air quality means for their health. To make it easier to understand, the AQI is divided into six levels of health concern, as presented in **Table 3**.

Table 3. The six levels of health concern into which the AQI is divided.

Air Quality Index (AQI) Values	Levels of Health Concern	Colours
0 to 50	Good	Green
51 to 100	Moderate	Yellow
101 to 150	Unhealthy for Sensitive Groups	Orange
151 to 200	Unhealthy	Red
201 to 300	Very Unhealthy	Purple
301 to 500	Hazardous	Maroon

The Air Quality Index (AQI) values for both PM₁₀ and PM_{2.5} sampled were determined using the AirNow AQI Calculator on AirNow Web site developed by USEPA and its federal, tribal, state, and local partners (available at: <http://www.airnow.gov/>). AQI values were determined by entering the concentration found from each sampling station into the AirNow App and clicking the calculate option on the right. The result for PM₁₀ revealed values as follows: D1 and D2: 78—moderately contaminated; D3: 104—undesirable; D4: 158—unhealthy; D5: out of reach (>500)—exceedingly hazardous; D6: 315—hazardous; D7: 491—hazardous; D8: out of reach (>500)—exceedingly hazardous; D9: 221—exceptionally unhealthy; and D10: out of reach (>500)—extremely hazardous. Also, the index values found for PM_{2.5} were D1: 113—undesirable for sensitive groups; D2: 137—undesirable; D3: 176—unhealthy; D4: 150—undesirable for sensitive groups; D5: 199, D6: 168, D7: 174, D8: 167; D9: 194—unhealthy; and D10: 134—undesirable for sensitive groups.

6. Conclusion and Recommendations

6.1. Conclusion

From the viewpoint of air quality studies conducted in KJMA, it is appropriate to say that the air quality in Koira Townships, Tensa, and Barsua has been highly degraded with PM_{10} and $PM_{2.5}$ on a daily basis. Results from the studies demonstrated that PM_{10} levels are far beyond the affirmed limits according to NAAQS at all the sampling sites. Essentially, $PM_{2.5}$ was observed to be high in several areas studied. The Air Quality Index (AQI) for PM_{10} displayed results ranging from moderately contaminated—D1 and D2; undesirable—D3; unhealthy—D4; exceptionally unhealthy—D9; hazardous—D6, D7; to extremely hazardous—D5, D8, and D10. Similarly, the index values found for $PM_{2.5}$ displayed results ranging from undesirable for sensitive groups—D1, D4, D10; undesirable—D2; unhealthy—D5, D6, D7, D8, D9, respectively. Additionally, significant concentrations of some metals and heavy metals were found using ICP-MS analysis, which revealed significant amounts of chemical constituents, some of which are hazardous to human wellbeing. Continuous exposure to this environment could give rise to prolonged respiratory illnesses such as silicosis, siderosis or welder's lung, damage to the heart and liver, and may catalyze radicals that are injurious to biological molecules, cells, tissues, and organisms. Thus, candid preventive and/or mitigation measures ought to be taken by the mine to reduce the levels of pollutants emanating from mining-related activities below acceptable or permissible threshold values or limits. The prime sources of PM discharge in the mining area and adjoining environment—Barsua, Tensa, and Koira—are the haul road networks used by more than 1500 dumpers during transportation of concentrates of iron ore, bauxite, manganese ore, etc., from the processing plant to train stations for shipment to steel plants.

From field observation and studies conducted, Koira Township is by far the most polluted with airborne particulates (PM_{10} and $PM_{2.5}$). Ambient Air Quality Monitoring (AAQM) studies carried out during morning and evening hours in the study area revealed that PM emission during the evening hours (5:00 pm to 6:00 am) is 10 times higher than those of the morning hours (7:00 am to 4:00 pm). This is due to the restriction on dumper movement during the morning hours; over 23 active mines in the studied area transport ore concentrate from 5:00 pm to 6:00 am, while dumpers are seen in a queue for loading from 7:00 am to 4:00 pm. Dumpers seen plying the road in the area are actually loaded with run of mines (ROM) from the production sites of mines to mineral processing plants for processing.

The presence of both primary and secondary forests in the study area, coupled with residential trees, helps to reduce PM levels before they reach sensitive zones. However, the magnitude of PM generation due to the constant stream of dumpers makes it tedious to contain PM in the area. The finer PM was observed to stay in suspension within the surrounding air for a much longer duration, traveling several kilometres from the discharge sources. As the PM emission is due to several

mines' workings, it is very difficult to effectively control the emission. Thus, collaborative effort is required from all mines and the State Pollution Control Board (SPCB) to effectively control and mitigate PM generation and concentration in the mining areas and the neighbouring environs.

6.2. Recommendations

The Barsua-Tensa-Koira mining corridor in Odisha has elevated PM₁₀ and PM_{2.5} concentrations, dangerous AQI levels, and a metal-enriched particle burden. Therefore, the following recommendations are necessary:

- Integrated dust control at haul roads and significant emission sources should be prioritized. Continuous mechanical sweeping and high-frequency water spraying using stationary and mobile mist cannons should be used along major transport corridors since haulage operations were found to be the main cause of particulate formation [2]. On unpaved roads, the use of environmentally friendly chemical dust suppressants can further lessen fine particle resuspension. To reduce turbulence-induced dust dispersion, strict enforcement of speed restrictions, controlled traffic scheduling, and staggered dumper movement are required, especially during peak nighttime operations (5:00 pm - 6:00 am) [37].
- Ore should be transported in covered vehicles, and dumpers should have regular maintenance to reduce exhaust and fugitive emissions. Engineering measures, including wind barriers, enclosures surrounding crushing and screening equipment, and dust extraction systems equipped with baghouse filters, should be built at operational sites. Conveyor transfer sites need to have localized suppression systems installed and sealed. Compaction, moisture conditioning, vegetative cover, and windbreak structures should be used to stabilize stockpiles, and concurrent backfilling and progressive mine reclamation should be used to reduce exposed surfaces that produce dust [38] [39].
- It is equally important to strengthen public health protections and environmental monitoring. In order to capture peak emission trends, seasonal and diurnal monitoring should be added to the establishment of Continuous Ambient Air Quality Monitoring Stations (CAAQMS) in sensitive receptors such as schools, hospitals, and residential areas. In townships, real-time AQI display devices would improve risk communication and community awareness. Workers and high-risk residents should have access to comprehensive occupational health surveillance programs that include biomonitoring for trace metal exposure, radiographic exams, and periodic pulmonary function tests. Enforcing the use of approved respiratory protection equipment is necessary, as is adhering to exposure limits that meet both national and international requirements [24] [25].
- Afforestation of reclaimed areas will support long-term environmental stability, and the expansion of multi-tier greenbelts utilizing native, dust-tolerant species along haul routes and mine peripheries can offer ecological buffering.

Cumulative effect evaluations covering all active mines should be required by regulatory bodies, and NAAQS compliance should be strengthened. Achieving long-term reductions in particulate pollution will require coordinated governance involving mining operators, the State Pollution Control Board, and community stakeholders, along with incentives for electric or low-emission haulage fleets and emission-based fines.

Immediate and coordinated mitigation actions are necessary due to the continuously high concentrations of PM₁₀ and PM_{2.5}, especially in Koira Township, and the known presence of hazardous trace elements. In order to protect the environment and public health, sustainable mining operations in the area will require integrated dust management, strict monitoring, enhanced occupational health protection, and vigorous regulatory enforcement.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

- [1] Katariya, N.K., Choudhary, B.S. and Pandey, P. (2024) Air Quality Predictions through Mathematical Modeling for Iron Ore Mine Project. *Applied Sciences*, **14**, Article 5922. <https://doi.org/10.3390/app14135922>
- [2] Sahoo, L.P. and Mangaraj, A. (2025) Impact of Mining on Air Quality and Its Management in Raikela Hill Range of Koira Tahasil Sundargarh District of Odisha. *Journal of Emerging Trends and Novel Research*, **3**, a159-a169.
- [3] Singh, D. and Verma, S.K. (2023) Impacts of Particulate Matter Pollution on Plants. In: *Environmental Science and Engineering*, Springer Nature Switzerland, 483-500. https://doi.org/10.1007/978-3-031-43729-8_17
- [4] Singh, R. and Singh, H. (2025) Analysing the Impact of Atmospheric Particulate Matter Deposition on Major Soil and Plants Attributes: A Review. *Water, Air, & Soil Pollution*, **236**, Article No. 814. <https://doi.org/10.1007/s11270-025-08472-3>
- [5] Live to Plant (2025) The Impact of Pollution on Plant Stomatal Function. https://livetoplant.com/the-impact-of-pollution-on-plant-stomatal-function/?utm_source=copilot.com#google_vignette
- [6] Pöschl, U. (2005) Atmospheric Aerosols: Composition, Transformation, Climate and Health Effects. *Angewandte Chemie International Edition*, **44**, 7520-7540. <https://doi.org/10.1002/anie.200501122>
- [7] Kampa, M. and Castanas, E. (2008) Human Health Effects of Air Pollution. *Environmental Pollution*, **151**, 362-367. <https://doi.org/10.1016/j.envpol.2007.06.012>
- [8] Hamanaka, R.B. and Mutlu, G.M. (2025) Particulate Matter Air Pollution: Effects on the Respiratory System. *Journal of Clinical Investigation*, **135**, e194312. <https://doi.org/10.1172/jci194312>
- [9] EPA (2016) Health and Environmental Effects of Particulate Matter (PM). <https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm>
- [10] Nishida, C. and Yatera, K. (2022) The Impact of Ambient Environmental and Occupational Pollution on Respiratory Diseases. *International Journal of Environmental Research and Public Health*, **19**, Article 2788. <https://doi.org/10.3390/ijerph19052788>

- [11] Grantz, D.A., Garner, J.H.B. and Johnson, D.W. (2003) Ecological Effects of Particulate Matter. *Environment International*, **29**, 213-239. [https://doi.org/10.1016/s0160-4120\(02\)00181-2](https://doi.org/10.1016/s0160-4120(02)00181-2)
- [12] Tanuja, K.V.T. and Narsing Rao, A.N.R. (2024) Specific Impact of Pollution and Health Scenario around Iron Ore Mining Area with Detailed Environmental Management Plan at Hospet Ballery Karnataka. *International Journal of Engineering and Science Invention*, **13**, 71-78.
- [13] Kuki, K.N., Oliva, M.A. and Pereira, E.G. (2008) Iron Ore Industry Emissions as a Potential Ecological Risk Factor for Tropical Coastal Vegetation. *Environmental Management*, **42**, 111-121. <https://doi.org/10.1007/s00267-008-9093-7>
- [14] Ashenden, T.W., Yunus, M. and Iqbal, M. (1997) Plant Response to Air Pollution. *The Journal of Applied Ecology*, **34**, Article 1513. <https://doi.org/10.2307/2405271>
- [15] Tang, J., Huang, Y., Sun, B., Song, Z. and Xu, A. (2024) Review of the Effects of Atmospheric Particulate Matter on Plants. *Chinese Journal of Ecology*, **43**, 254-263. (In Chinese)
- [16] Naidoo, G. and Chirkoot, D. (2004) The Effects of Coal Dust on Photosynthetic Performance of the Mangrove, *Avicennia Marina* in Richards Bay, South Africa. *Environmental Pollution*, **127**, 359-366. <https://doi.org/10.1016/j.envpol.2003.08.018>
- [17] Musah, B.I. (2024) Effects of Heavy Metals and Metalloids on Plant-Animal Interaction and Biodiversity of Terrestrial Ecosystems—An Overview. *Environmental Monitoring and Assessment*, **197**, Article No. 12. <https://doi.org/10.1007/s10661-024-13490-5>
- [18] Petavratzi, E., Kingman, S. and Lowndes, I. (2005) Particulates from Mining Operations: A Review of Sources, Effects and Regulations. *Minerals Engineering*, **18**, 1183-1199. <https://doi.org/10.1016/j.mineng.2005.06.017>
- [19] Singh, R., Verma, A.K. and Prakash, S. (2023) The Web of Life: Role of Pollution in Biodiversity Decline. *International Journal of Fauna and Biological Studies*, **10**, 49-52. <https://doi.org/10.22271/23940522.2023.v10.i3a.1003>
- [20] Kayalar, Ö., Rajabi, H., Konyalilar, N., Mortazavi, D., Aksoy, G.T., Wang, J., *et al.* (2024) Impact of Particulate Air Pollution on Airway Injury and Epithelial Plasticity; Underlying Mechanisms. *Frontiers in Immunology*, **15**, Article ID: 1324552. <https://doi.org/10.3389/fimmu.2024.1324552>
- [21] Afthab, M., Hambo, S., Kim, H., Alhamad, A. and Harb, H. (2024) Particulate Matter-Induced Epigenetic Modifications and Lung Complications. *European Respiratory Review*, **33**, Article 240129. <https://doi.org/10.1183/16000617.0129-2024>
- [22] Liu, Y., Xu, F., Liu, W., Liu, X. and Wang, D. (2025) Characteristics, Sources, Exposure, and Health Effects of Heavy Metals in Atmospheric Particulate Matter. *Current Pollution Reports*, **11**, Article No. 16. <https://doi.org/10.1007/s40726-025-00344-y>
- [23] Wan Mahiyuddin, W.R., Ismail, R., Mohammad Sham, N., Ahmad, N.I. and Nik Hassan, N.M.N. (2023) Cardiovascular and Respiratory Health Effects of Fine Particulate Matters (PM_{2.5}): A Review on Time Series Studies. *Atmosphere*, **14**, Article 856. <https://doi.org/10.3390/atmos14050856>
- [24] Orellano, P., Kasdagli, M., Pérez Velasco, R. and Samoli, E. (2024) Long-Term Exposure to Particulate Matter and Mortality: An Update of the WHO Global Air Quality Guidelines Systematic Review and Meta-Analysis. *International Journal of Public Health*, **69**, Article 1607683. <https://doi.org/10.3389/ijph.2024.1607683>
- [25] Hou, X., Wei, Z., Jiang, X., Wei, C., Dong, L., Li, Y., *et al.* (2025) A Comprehensive Retrospect on the Current Perspectives and Future Prospects of Pneumoconiosis.

- Frontiers in Public Health*, **12**, Article 1435840.
<https://doi.org/10.3389/fpubh.2024.1435840>
- [26] Stege, T.A.M., Bolte, J.F.B., Claassen, L. and Timmermans, D.R.M. (2022) Particulate Matter in the Workplace: Effects of a Mental Models-Based Folder Combined with a Practical Assignment. *BMC Public Health*, **22**, Article No. 968.
<https://doi.org/10.1186/s12889-022-13362-y>
- [27] Ronen, A. (2025) Visibility-Based Calibration of Low-Cost Particulate Matter Sensors: Laboratory Evaluation and Theoretical Analysis. *Sensors*, **25**, Article 6995.
<https://doi.org/10.3390/s25226995>
- [28] Khan, M.M.H., Kurniawan, T.A., Chandra, I. and Lei, T.M.T. (2025) Modeling PM10 Emissions in Quarry and Mining Operations: Insights from AERMOD Applications in Malaysia. *Atmosphere*, **16**, Article 369. <https://doi.org/10.3390/atmos16040369>
- [29] Anjali, K., Ray, S.K., Pandey, J. and Pandey, J.K. (2025) Dust Generation and Dust Exposure Profiling for Various Category of Workers in Hutti Gold Mines—A Case Study. In: Sinha, A., Sarkar, B.C. and Mandal, P.K., Eds., *Springer Proceedings in Earth and Environmental Sciences*, Springer, 899-906.
https://doi.org/10.1007/978-3-032-09929-7_66
- [30] Duran, Z. and Erdem, B. (2026) Modeling of Particulate Matter Concentrations from Hauling Operations in Quarries Using Decision Tree Approach. *Air Quality, Atmosphere & Health*, **19**, 899-906. <https://doi.org/10.1007/s11869-026-01894-w>
- [31] Solaimani, K. and Yousefi-Kebriya, A. (2026) Remote Sensing Assessment of Dust Pollution from Mining Activities in Haraz Basin, Iran. *International Journal of Environmental Science and Technology*, **23**, Article No. 293.
<https://doi.org/10.1007/s13762-026-07088-2>
- [32] Stryhunivska, O., Zwolińska, B. and Giel, R. (2024) The Management of Harmful Emissions from Heavy-Duty Transport Towards Sustainable Development. *Sustainability*, **16**, Article 10988. <https://doi.org/10.3390/su162410988>
- [33] Komti, A., Jbara, A., Kechiche, N., Khardi, S. and Slimi, K. (2025) Study of Airborne Particulate Pollution from Road Traffic Emissions in the Coastal Urban Center of Sousse City, Tunisia. *International Journal of Environmental Research*, **19**, Article No. 245. <https://doi.org/10.1007/s41742-025-00918-0>
- [34] Chaulya, S.K., Singh, S.K., Singh, S., Mondal, G.C., Singh, R.K. and Shekhar, S. (2025) Integrated Air Quality Prediction and Mitigation Strategies for Sustainable Mining Operations in India. *Air Quality, Atmosphere & Health*, **18**, 1615-1633.
<https://doi.org/10.1007/s11869-025-01720-9>
- [35] Kasa, V.P., Samal, B., Mittal, C., Dubey, B.K., Das, S., Sahu, S.K., *et al.* (2025) Respiratory Health Impacts of Opencast Coal Mining in India: An Epidemiological Study. *Air Quality, Atmosphere & Health*, **18**, 3915-3929.
<https://doi.org/10.1007/s11869-025-01847-9>
- [36] Kumar, M., Swain, S.K., Parida, B.R., Panda, A. and Dwivedi, C.S. (2025) Evaluating Impacts of Opencast Mining of Gondwana Coalfield (India) on Environment and Socioeconomic Using Multitemporal Satellite Data. *Discover Geoscience*, **3**, Article No. 31. <https://doi.org/10.1007/s44288-025-00140-7>
- [37] Barsua Iron Ore Mines, Tensa—OSPCB (2026) Air Quality Near Barsua Iron Ore Mines, Tensa—OSPCB, Tensa.
<https://www.iqair.com/ca/india/odisha/tensa/barsua-iron-ore-mines-tensa-ospcb>
- [38] Assefa, F.G., Xiang, L., Yang, Z., Gebretsadik, A., Wahab, A., Fisha, Y., *et al.* (2025) Research on Dust Concentration and Migration Mechanisms on Open-Pit Coal Mining Roads: Effects of Meteorological Conditions and Haul Truck Movements. *Min-*

ing, 5, Article 43. <https://doi.org/10.3390/mining5030043>

- [39] Kashi, V.K., Sahu, A.R. and Krishnamoorthi, S. (2025) A Laboratory Evaluation of Haul Road Dust Suppression Using Water Soluble PAM & PAM-co-PAMPS Polymers. *Aerosol Science and Engineering*.
https://link.springer.com/article/10.1007/s41810-025-00357-6?utm_source=copylot.com