Environmental Impact Assessment of PM_{10} Dispersion from Multiple Industrial Emission Sources under Ambient Meteorological Conditions Using AERMOD: An Industrial Case Study

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Abstract-

Environmental Impact Assessment (EIA) is an essential tool for evaluating the potential effects of industrial activities on ambient air quality and ensuring compliance with environmental regulations. Atmospheric dispersion modelling has become an integral component of air quality impact assessment, enabling quantitative prediction of pollutant concentrations under prevailing meteorological conditions. This study presents an environmental impact assessment of PM_{10} emissions from multiple industrial emission sources using the United States Environmental Protection Agency (US EPA) AERMOD dispersion model. To maintain industrial confidentiality, the identity and location of the study facility have been withheld. The assessment considered three major emission categories, namely area sources, point sources, and transport-related fugitive emissions. Site-specific meteorological data were processed using AERMET, while terrain information was incorporated through AERMAP to simulate pollutant dispersion over a 10 km × 10 km receptor domain. Individual and cumulative ground-level PM_{10} concentrations were predicted under ambient meteorological conditions and evaluated against applicable ambient air quality standards. The modelling results indicated that ground-level fugitive emissions from area and transport sources contributed significantly more to ambient PM_{10} concentrations than elevated stack emissions. The cumulative predicted concentration remained within the prescribed regulatory limits, indicating no significant adverse air quality impacts under the assessed operating conditions. The study demonstrates that AERMOD provides a reliable framework for environmental impact assessment of industrial air emissions and supports informed decision-making for pollution control, environmental management, and regulatory compliance.

Keywords: *Environmental Impact Assessment; Air Quality Impact Assessment; AERMOD; PM_{10} Dispersion; Industrial Air Emissions; Atmospheric Dispersion Modelling; Fugitive Dust; Ambient Meteorology; Environmental Compliance.*

1. Introduction

Environmental Impact Assessment (EIA) has become one of the most important environmental management tools for ensuring that industrial development proceeds in an environmentally sustainable manner. By systematically identifying, predicting, and evaluating the potential environmental consequences of proposed or existing projects, EIA supports informed decision-making, regulatory compliance, and implementation of appropriate mitigation measures [1,2]. Among the various environmental components evaluated during EIA, ambient air quality is of particular importance because atmospheric pollutants can directly affect human health, ecosystems, infrastructure, and regional environmental quality. Consequently, quantitative air quality impact assessment has become an integral component of environmental clearance studies for industrial projects worldwide [3].

Industrialization, urban expansion, increasing energy demand, and intensified transportation activities have substantially increased atmospheric pollutant emissions during the past several decades. Particulate matter (PM), particularly particulate matter having an aerodynamic diameter less than 10 µm (PM_{10}), is recognised as one of the most significant criteria pollutants because of its persistence in the atmosphere and its ability to penetrate the human respiratory system [4]. Numerous epidemiological investigations have established strong associations between long-term PM exposure and respiratory diseases, cardiovascular disorders, reduced lung function, and premature mortality [4,5].

Industrial facilities generate PM_{10} from multiple emission categories including elevated point sources, process operations, material handling, waste management activities, internal transportation, and exposed working surfaces. Fugitive emissions released close to ground level frequently contribute more to local ambient particulate concentrations than elevated stack emissions because they undergo comparatively limited initial atmospheric dilution [6]. Accurate identification of source contributions is therefore essential for environmental management, regulatory compliance, and effective pollution control planning.

Conventional ambient monitoring provides valuable information on existing air quality conditions but cannot adequately predict the spatial distribution of pollutant concentrations under varying operational and meteorological scenarios. Atmospheric dispersion modelling therefore serves as a complementary predictive tool that estimates ground-level pollutant concentrations using source characteristics, terrain information, and site-specific meteorological observations. Within the EIA framework, dispersion modelling enables assessment of cumulative impacts, identification of sensitive receptors, evaluation of alternative operational scenarios, and demonstration of compliance with ambient air quality standards [3,7].

Among the available regulatory dispersion models, the EPA AERMOD modelling system has become one of the most widely accepted tools for near-field industrial air quality assessment. AERMOD incorporates planetary boundary layer parameterization, terrain effects, atmospheric stability, and multiple source representations to simulate pollutant transport and dispersion under realistic atmospheric conditions [8,9]. Owing to its scientific robustness and regulatory acceptance, AERMOD has been extensively applied in environmental impact assessments, industrial compliance studies, environmental permitting, and pollution control planning [10].

Previous studies have successfully applied AERMOD to assess emissions from thermal power plants, mining operations, cement industries, petrochemical facilities, transportation corridors, airports, municipal solid waste landfills, and waste management facilities [6,10,11]. Nevertheless, comparatively fewer investigations have simultaneously evaluated point sources, area sources, and transport-related fugitive emissions within a unified Environmental Impact Assessment framework while demonstrating how modelling outputs support mitigation planning and regulatory decision-making [3].

Therefore, the present study performs an Environmental Impact Assessment of PM_{10} dispersion from multiple industrial emission sources using the US EPA AERMOD model under representative ambient meteorological conditions. The study integrates emissions from point, area, and transport-related sources within a single modelling framework to predict cumulative ground-level PM_{10} concentrations and evaluate environmental compliance. The proposed methodology further demonstrates the practical application of atmospheric dispersion modelling as a decision-support tool for environmental management and sustainable industrial development.

2. Literature Review

2.1 Environmental Impact Assessment and Air Quality Assessment

Environmental Impact Assessment provides a structured framework for identifying, predicting, evaluating, and mitigating environmental impacts associated with developmental activities before project implementation [1,2]. Air quality assessment has become one of the principal technical components of EIA because atmospheric pollutants may affect public health, ecosystems, agricultural productivity, and surrounding communities beyond project boundaries. Consequently, regulatory authorities increasingly recommend quantitative air quality prediction using atmospheric dispersion models rather than relying solely on ambient monitoring [3,7].

2.2 PM_{10} Emissions from Industrial Facilities

PM_{10} remains one of the most important criteria pollutants considered during industrial environmental assessments because of its persistence in the atmosphere and its documented adverse health impacts [4]. Industrial PM_{10} originates from combustion processes as well as fugitive activities including raw material handling, transportation, stockpiles, landfill operations, and wind-induced resuspension of deposited dust [6]. Several investigations have demonstrated that ground-level fugitive emissions often contribute more significantly to local ambient particulate concentrations than elevated stack emissions owing to limited atmospheric dilution immediately after release [6,11].

2.3 Atmospheric Dispersion Modelling in Environmental Impact Assessment

Atmospheric dispersion models mathematically simulate pollutant transport, atmospheric diffusion, deposition, and ground-level concentration distributions using emission characteristics, meteorological observations, and terrain information [12]. Compared with field monitoring, dispersion modelling enables prediction of pollutant concentrations over extensive receptor networks under multiple operational scenarios, making it particularly valuable during environmental impact assessment where future environmental conditions must be evaluated before project implementation [7].

Several regulatory dispersion models have been developed, including ISCST3, AERMOD, CALPUFF, and Computational Fluid Dynamics (CFD) models. Among these, AERMOD has become the preferred regulatory model for near-field industrial applications because of its improved treatment of atmospheric boundary layer processes, terrain effects, and multiple emission source configurations [8,9].

2.4 Applications of AERMOD in Industrial Environmental Assessment

Since its regulatory adoption, AERMOD has been successfully applied to thermal power plants, mining operations, cement industries, petrochemical facilities, airports, transportation corridors, municipal solid waste landfills, waste incinerators, and integrated waste management facilities [6,11]. Recent investigations have expanded its application through integration with satellite observations, advanced meteorological modelling, health risk assessment, and geographic information systems to improve environmental impact assessment and pollution management [10,13].

2.5 Research Gap

Although atmospheric dispersion modelling has been widely applied in industrial air quality studies, comparatively fewer investigations have simultaneously assessed point sources, area sources, and transport-related fugitive emissions within an integrated Environmental Impact Assessment framework. Most published studies evaluate individual source categories or specific industrial processes, limiting comprehensive understanding of cumulative environmental impacts [11,3].

Furthermore, relatively limited literature explicitly demonstrates how AERMOD outputs can be translated into environmental management strategies, source prioritisation, and mitigation planning for complex industrial facilities. The present study addresses this gap by integrating multiple industrial emission sources into a unified Environmental Impact Assessment framework, thereby providing a practical methodology for environmental compliance assessment and evidence-based pollution control.

3. Methodology

3.1 Study Framework

The present investigation was conducted within the framework of an Environmental Impact Assessment (EIA) to evaluate the potential effects of industrial PM_{10} emissions on ambient air quality. The assessment followed the conventional sequence adopted in air quality impact studies, comprising emission inventory development, meteorological data processing, terrain characterization, atmospheric dispersion modelling, prediction of ground-level concentrations, and evaluation of environmental compliance [7,2].

To preserve industrial confidentiality, the identity and geographical location of the study facility have not been disclosed. The investigated facility represents a large integrated industrial installation comprising multiple operational units capable of generating particulate matter through both process-related and fugitive emission activities.

3.2 Study Area

The assessment domain consisted of a 10 km × 10 km receptor grid centred on the industrial facility, consistent with regulatory guidance for near-field dispersion modelling. The receptor network was designed to capture both near-source and far-field pollutant concentrations while considering prevailing meteorological conditions and local terrain characteristics.

Digital elevation data were incorporated into the modelling system using the US EPA AERMAP preprocessor to account for terrain-induced influences on plume behaviour. The surrounding land use was characterized primarily by industrial operations with scattered open land and transportation corridors.

3.3 Emission Source Characterization

PM_{10} emissions were classified into three principal categories based on source geometry and operational characteristics.

(i) Area Sources

Area sources represented ground-level emission activities distributed over relatively large surface areas. These included landfill operations, material handling areas, storage yards, and exposed operational surfaces where particulate emissions occur due to wind erosion and routine industrial activities.

(ii) Point Sources

Point sources consisted of elevated process stacks associated with industrial operations. For each stack, emission rate, stack height, stack diameter, exit temperature, and exit velocity were incorporated into the dispersion model according to operational records.

(iii) Transport-related Fugitive Sources

Transport-related emissions originated from internal vehicular movement along paved and unpaved roads within the industrial premises. These emissions were treated as ground-level sources because of continuous dust resuspension generated by heavy vehicle movement.

The integrated consideration of point, area, and transport-related emissions enabled evaluation of both individual source contributions and cumulative environmental impacts.

3.4 Emission Inventory Development

A comprehensive emission inventory was developed using operational information provided by the industrial facility. PM_{10} emission rates for process stacks were obtained from stack monitoring records, whereas emissions from landfill activities and transport operations were estimated using internationally accepted emission estimation procedures and operational activity data.

The emission inventory incorporated source-specific operating schedules, emission characteristics, spatial coordinates, release heights, and source dimensions required for AERMOD simulations. Development of a representative emission inventory is widely recognised as the most critical component of atmospheric dispersion modelling because prediction accuracy largely depends on reliable source characterization [8].

3.5 Meteorological Data Processing

Atmospheric dispersion is strongly influenced by meteorological conditions governing plume transport, atmospheric stability, vertical mixing, and pollutant dilution. Therefore, site-specific surface meteorological observations were processed using the US EPA AERMET meteorological preprocessor.

Meteorological parameters considered in the assessment included wind speed, wind direction, ambient temperature, atmospheric stability, cloud cover, mixing height, and surface characteristics. These parameters were subsequently converted into boundary layer variables required by AERMOD for simulation of atmospheric dispersion.

Terrain elevations within the modelling domain were processed using the US EPA AERMAP terrain preprocessor to account for topographic influences on pollutant dispersion.

3.6 AERMOD Configuration

Atmospheric dispersion simulations were performed using the US EPA AERMOD modelling system. The model applies steady-state Gaussian plume theory combined with advanced planetary boundary layer parameterization to estimate ground-level pollutant concentrations under varying meteorological conditions [8,9].

The modelling configuration incorporated:

- Point, area, and transport-related emission sources;
- Site-specific meteorological data processed through AERMET;
- Terrain elevations generated using AERMAP;
- A Cartesian receptor network covering the entire assessment domain; and
- Regulatory default options recommended by the US EPA.

The model predicted individual source contributions together with cumulative PM_{10} concentrations at all receptor locations.

3.7 Air Quality Impact Assessment

Predicted ground-level PM_{10} concentrations obtained from AERMOD were analysed to identify maximum concentration locations, dominant emission sources, and cumulative environmental impacts across the study domain.

Environmental significance was evaluated by comparing cumulative predicted concentrations with the applicable National Ambient Air Quality Standards (NAAQS) prescribed for PM_{10}. Individual source contributions were also analysed to determine the relative influence of process stacks, landfill operations, and transport-related activities on ambient particulate concentrations.

The modelling outputs further supported identification of appropriate mitigation measures including dust suppression, improved housekeeping, road maintenance, emission control, and greenbelt development.

3.8 Model Assumptions and Limitations

The present assessment is based on several assumptions commonly adopted in regulatory atmospheric dispersion modelling. The simulations assume representative operating conditions throughout the assessment period, constant source characteristics, and accurate meteorological observations. Although AERMOD incorporates advanced atmospheric boundary layer physics, prediction uncertainty remains influenced by emission inventory quality, temporal variability of industrial operations, and inherent uncertainties associated with meteorological measurements.

Nevertheless, AERMOD is internationally recognised as one of the most reliable regulatory dispersion models for near-field industrial air quality assessments and has been extensively validated for environmental impact assessment applications [6,7].

4. Results and Discussion

4.1 Environmental Impact Assessment Framework

The environmental impact assessment was undertaken to evaluate the contribution of multiple industrial emission sources to ambient PM_{10} concentrations under representative meteorological conditions. Atmospheric dispersion modelling was performed using the US EPA AERMOD modelling system, incorporating emissions from area sources, point sources, and transport-related fugitive activities within a common modelling domain. The assessment focused on identifying the dominant emission sources, predicting cumulative ground-level concentrations, evaluating compliance with applicable ambient air quality standards, and recommending suitable mitigation measures.

4.2 Source-wise Contribution to PM_{10} Concentration

Simulation results demonstrated that PM_{10} concentrations varied considerably among different emission categories because of differences in source geometry, release height, emission characteristics, and atmospheric dispersion behaviour.

Ground-level area sources associated with industrial operations generated the highest local PM_{10} concentrations. These emissions were characterised by limited plume rise and reduced atmospheric dilution immediately after release, resulting in comparatively higher near-field ground-level concentrations.

Transport-related fugitive emissions also contributed substantially to ambient PM_{10} levels because continuous vehicular movement promoted resuspension of deposited dust along internal roads. The magnitude of these emissions varied according to traffic intensity, surface condition, and prevailing wind speed.

In contrast, emissions released through elevated process stacks produced comparatively lower ground-level concentrations despite higher emission rates. Effective plume rise and enhanced atmospheric dilution reduced their contribution within the immediate vicinity of the facility as shown in table 1.

These observations are consistent with previous investigations reporting that fugitive emissions frequently dominate local particulate pollution in industrial complexes [6,11].

Table 1. Summary of predicted maximum PM_{10} concentrations from individual emission sources.

Emission Sources	PM_{10} Concentrations
Point Sources	5.99 $\mu g/m^3$
Area Sources	52.76 $\mu g/m^3$
Transport-related fugitive emissions	34.05 $\mu g/m^3$
All Sources	77.2 $\mu g/m^3$

4.3 Spatial Distribution of PM_{10}

The predicted PM_{10} concentration contours demonstrated clear spatial variability throughout the assessment domain. Maximum concentrations occurred near active operational areas where ground-level emissions were concentrated. Concentrations gradually decreased with increasing distance from the emission sources owing to atmospheric dispersion and dilution.

The contour patterns closely followed the prevailing wind direction observed during the study period, indicating that meteorological conditions exerted a significant influence on pollutant transport. Areas located downwind of the facility exhibited comparatively higher predicted concentrations, whereas receptors situated upwind experienced substantially lower impacts as shown in figure 1.

Although individual emission sources produced distinct concentration patterns, cumulative modelling indicated overlapping dispersion zones in portions of the study area where multiple plumes interacted.

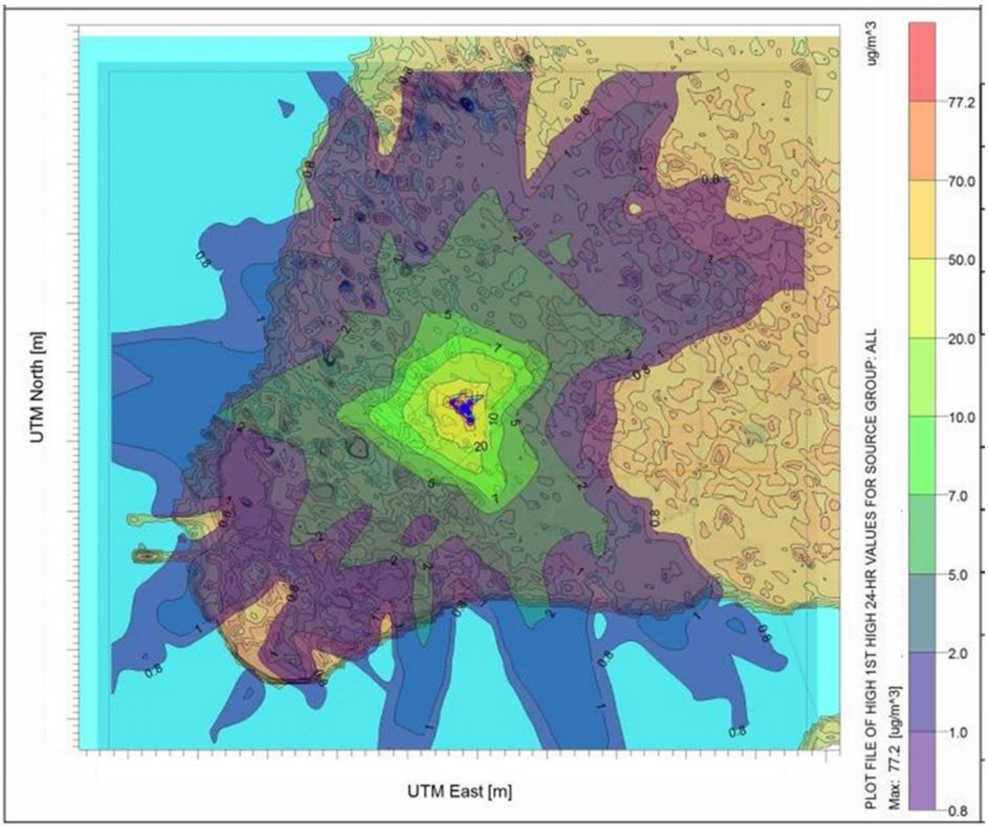

Figure 1. Predicted cumulative PM_{10} concentration contours generated using AERMOD.

4.4 Influence of Ambient Meteorological Conditions

Meteorological conditions strongly influenced atmospheric dispersion throughout the simulation period. Wind speed and wind direction governed horizontal pollutant transport, whereas atmospheric stability controlled vertical mixing and plume dilution.

Lower wind speeds combined with stable atmospheric conditions produced relatively higher ground-level PM_{10} concentrations because pollutant dispersion was restricted. Conversely, higher wind speeds enhanced atmospheric dilution and reduced local particulate accumulation as shown in figure 2.

These observations demonstrate the importance of incorporating site-specific meteorological information during Environmental Impact Assessment rather than relying solely on emission characteristics.

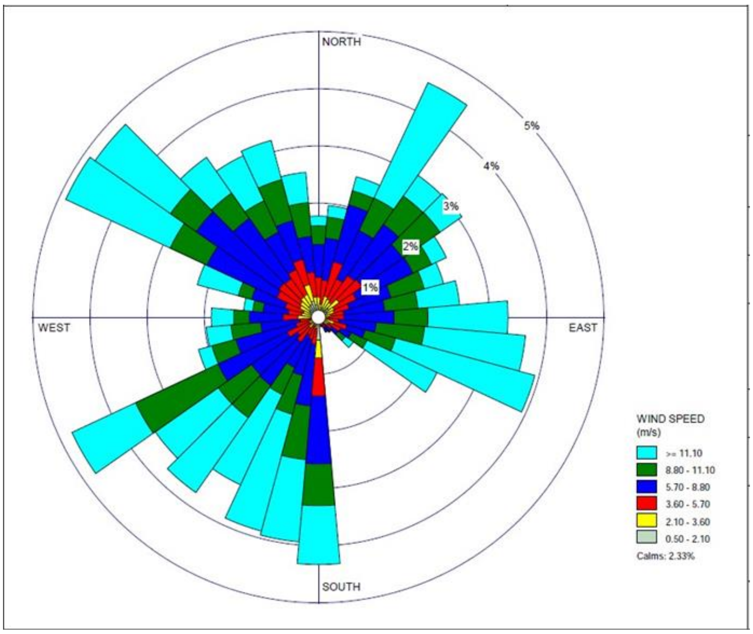

Figure 2. Wind rose representing prevailing meteorological conditions

4.5 Environmental Compliance Assessment

The cumulative PM_{10} concentration predicted by AERMOD remained within the applicable National Ambient Air Quality Standards (NAAQS), indicating that routine industrial operations are unlikely to produce significant adverse impacts on ambient air quality under the simulated operating conditions as shown in table 2.

Although compliance with regulatory standards was achieved, the modelling results clearly identified landfill activities and transport-related fugitive emissions as the dominant contributors to local particulate concentrations. These findings suggest that future environmental management efforts should prioritise dust suppression, improved road maintenance, optimisation of vehicle movement, regular housekeeping, and enhancement of greenbelt development rather than focusing exclusively on stack emission control.

This demonstrates the practical value of atmospheric dispersion modelling as an environmental decision-support tool, enabling prioritisation of pollution control strategies based on quantitative source contribution analysis.

Table 2. Comparison of predicted cumulative PM_{10} concentration with applicable ambient air quality standards.

Parameters	Concentration in Ambient Air GPCB Guidelines	Concentration in Ambient Air Actual
	24 Hrs. Average	**24 Hrs. Average**
Particulate matter-10 (PM10)	100 µg/m^3	77.2 µg/m^3

4.6 Comparison with Previous Studies

The present findings agree well with published investigations reporting that fugitive emissions frequently represent the dominant source of particulate pollution in industrial environments despite comparatively lower emission heights [6,11].

Similarly, recent applications of AERMOD have demonstrated that realistic source representation combined with site-specific meteorological processing substantially improves prediction reliability and supports regulatory environmental assessment [10]. The present investigation extends these previous studies by integrating multiple emission categories within a single Environmental Impact Assessment framework and evaluating their cumulative contribution to ambient PM_{10} concentrations.

The methodology presented in this study therefore provides a practical approach for environmental clearance studies, industrial compliance assessment, and pollution management planning where multiple emission sources operate simultaneously.

Finally, the performance indicators of each class in each of the tests performed, i.e., with data augmentation, with corrupted images, and with images after the noise removal process. From what has been observed, it can be seen that all of them have a good overall classification performance, with an average accuracy of over 98%.

5. Conclusion

The present study demonstrated the application of the US EPA AERMOD dispersion model as an effective tool for EIA of PM_{10} emissions from an integrated industrial facility comprising multiple emission sources. By integrating emissions from area sources, point sources, and transport-related fugitive activities within a unified modelling framework, the study provided a comprehensive assessment of ambient air quality impacts under representative meteorological conditions.

The modelling results indicated that ground-level fugitive emissions associated with operational areas and internal transportation contributed more significantly to ambient PM_{10} concentrations than elevated stack emissions. The predicted cumulative ground-level PM_{10} concentration remained within the applicable National Ambient Air Quality Standards (NAAQS), suggesting that routine industrial operations are unlikely to produce significant adverse impacts on ambient air quality under the assessed operating conditions. Nevertheless, the analysis identified fugitive dust emissions as the primary contributor to local particulate concentrations, highlighting the importance of targeted mitigation measures such as dust suppression, improved housekeeping, regular road maintenance, optimized vehicular movement, and effective greenbelt development.

From an Environmental Impact Assessment perspective, the study demonstrates that atmospheric dispersion modelling provides a scientifically robust and transparent approach for predicting pollutant dispersion, evaluating regulatory compliance, identifying environmentally sensitive areas, and prioritizing pollution control strategies before and during industrial operation. The integration of source-specific emission inventories with site-specific meteorological and terrain data enhances the reliability of environmental decision-making and supports sustainable industrial management.

Although the assessment represents typical operating conditions and employs internationally accepted regulatory modelling procedures, prediction uncertainty remains dependent on the quality of emission inventories, meteorological observations, and operational variability. Future investigations may incorporate seasonal emission variability, continuous meteorological datasets, model validation using field observations, and health risk assessment to further strengthen environmental impact prediction.

Overall, the proposed methodology provides a practical and transferable framework for air quality impact assessment of industrial facilities and can support environmental clearance studies, regulatory compliance, pollution management, and sustainable industrial development.

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