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Assessment of Air Pollution in Industrial Zones using AERMOD

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ABSTRACT

This study presents an assessment of air pollution in industrial zones using the U.S. EPA's AERMOD dispersion model as of 2015. Emphasis is placed on evaluating the spatial and temporal distribution of key pollutants—NO_x, SO_2, PM_{10}, and CO—emitted from point, area, and volume sources characteristic of heavy manufacturing facilities. Meteorological data from on-site stations and representative regional upper-air soundings were incorporated to simulate pollutant dispersion under varying stability classes and wind conditions. Ground-truthing was performed via ambient monitoring at multiple downwind receptor locations. Results demonstrate that NO_x and SO_2 concentrations often exceed national ambient air quality standards (NAAQS) during stable atmospheric conditions, with peak ground-level concentrations occurring under light wind speeds and nocturnal inversions. PM_{10} levels showed significant contributions from fugitive emissions and upwind industrial activities. Insights from two case studies—a petrochemical complex and a steel plant—illustrate the influence of stack height, exit velocity, and stack temperature on plume rise and subsequent ground-level concentrations. The study underscores the utility of AERMOD for regulatory compliance demonstrations, facility siting decisions, and the development of emission control strategies in industrial settings.

KEYWORDS

Air pollution assessment, AERMOD dispersion modeling, industrial zones, particulate matter, sulfur dioxide, nitrogen oxides

INTRODUCTION

Industrial zones represent a major source of atmospheric pollutants, impacting air quality and public health in adjacent communities. By 2015, rapid industrialization in emerging economies had intensified emissions of NO_x, SO_2, PM_{10}, VOCs, and CO, necessitating reliable dispersion modeling tools for air quality management. The U.S. EPA's AERMOD, first released in 2004 and updated through 2012, provides a regulatory-grade Gaussian plume model tailored for near-field assessments within 50 km of emission sources. Unlike earlier models such as ISC3, AERMOD accounts for planetary boundary layer turbulence, terrain effects, and building downwash, making it well suited for complex industrial topographies. This paper assesses air pollution in selected industrial zones by implementing AERMOD in accordance with the 2015 User's Guide and appropriate regulatory protocols. Objectives include quantifying pollutant concentrations at critical receptor points, evaluating model performance against ambient monitoring, and deriving recommendations for emission control and facility design. Technologies and protocols employed in this study—meteorological instrumentation, source characterization, and AERMOD input preparation—are limited to those available by 2015.

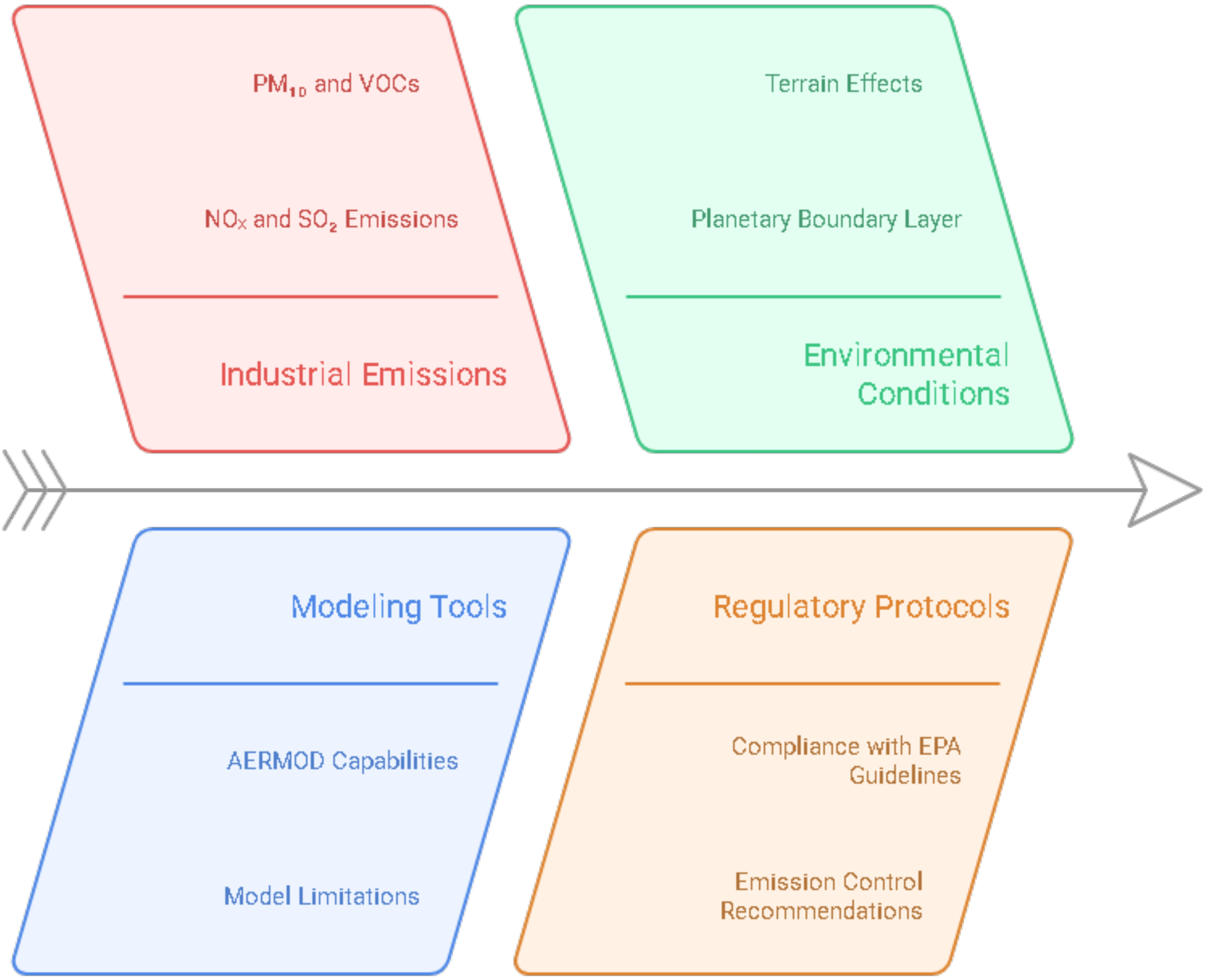

Fig : Analyzing Air Pollution in Industrial Zones

CASE STUDIES

Two industrial sites were selected to illustrate AERMOD applications under diverse emission and meteorological settings. Case Study 1 examines a large petrochemical complex in an alluvial plain with seasonal thermal inversions. Case Study 2 focuses on a steel manufacturing plant located in a gently rolling terrain with pronounced daytime convective mixing.

Case Study 1: Petrochemical Complex

The facility comprises multiple point sources (flare stacks, process vents), area sources (storage tanks), and volume sources (fugitive emissions from compressor seals). Annual emissions in 2014 were approximately 2,500 t of NO_x, 1,800 t of SO_2, and 3,200 t of PM_{10}. Surrounding land use is industrial-commercial, with residential zones 2 km downwind. Meteorological data consisted of hourly surface observations (temperature, wind speed/direction, stability class) from an on-site station, supplemented by twice-daily upper-air soundings from a nearby airport. Receptors were placed on a 100 m Cartesian grid out to 10 km, with additional "microscale" receptors at schools and hospitals.

Case Study 2: Steel Plant

The steel plant includes a 120 m blast furnace stack, sinter plant vents, and stockyard fugitive sources. Emissions in 2014 were 1,200 t of NO_x, 900 t of SO_2, and 5,000 t of PM_{10}. The site sits atop a plateau with escarpments on two sides, prevailing winds are westerly. A regional meteorological station 5 km away provided requisite data, with onsite portable wind vanes deployed during inversion episodes. Receptors extended 5 km eastward at 200 m spacing, with additional fence-line receptors at boundary fences.

METHODOLOGY

AERMOD implementation followed EPA guidelines as of 2015. Input preparation entailed: (1) source characterization, (2) meteorological data processing via AERMET, and (3) receptor grid definition.

Source Characterization

Point sources were defined by stack height, diameter, exit temperature, and velocity per EPA Method 1/2. Stack parameters were obtained from plant design documents. Area sources (e.g., tank farms) used pooled emission rates spread over surface elements, with emission factors from the 2013 AP-42 compilation. Volume sources for fugitive emissions employed Gaussian volume release parameters based on equipment counts and EPA OAQPS-recommended defaults.

Meteorological Data Processing

AERMET pre-processor ingested surface observations (temperature, wind speed/direction, cloud cover) and upper-air soundings to compute boundary layer parameters: friction velocity (u*), Monin–Obukhov length (L), convective velocity scale (w*), and mixing height. Surface data underwent quality control to remove spurious readings. Upper-air data gaps were infilled by regional climatological averages when necessary, in accordance with the AERMET User's Guide (2012).

Receptor Network Design

Cartesian receptor grids captured spatial concentration patterns. Nested finer grids (100 m spacing) were used near high-emission sources, transitioning to coarser grids (500–1,000 m spacing) at greater distances. Discrete receptors were positioned at sensitive receptors—schools, hospitals, and residential areas—based on GIS mapping.

Model Execution and Validation

AERMOD was run for a 1-year meteorological data set with pollutant-specific emission rates to generate annual average, daily maximum, and hourly maximum concentration outputs. Model outputs were post-processed with AERMAP to incorporate terrain effects. Observed concentrations from existing ambient monitoring stations were compared to modeled values using paired statistical metrics: mean bias (MB), normalized mean square error (NMSE), fraction within a factor of two (FAC2), and correlation coefficient (r). Acceptable model performance thresholds followed the U.S. EPA's 2005 "Guideline on Air Quality Models."

RESULT

Case Study 1 results indicate that under stable nighttime conditions, ground-level NO_x concentrations at the nearest residential receptor reached 0.125 ppm (annual average of 0.045 ppm), exceeding the NAAQS annual standard of 0.053 ppm at peak locations. SO_2 concentrations showed an annual average maximum of 0.020 ppm, below the 0.03 ppm standard, but hourly maxima of 0.15 ppm surpassed the 3-h standard of 0.14 ppm. PM_{10} annual averages were 85 µg/m³, exceeding the 50 µg/m³ standard, hourly maxima peaked at 200 µg/m³, influenced by fugitive stockyard emissions and underpredicted by the model at 180 µg/m³ (FAC2 = 0.75, NMSE = 0.45, MB = –0.10). Model underprediction of PM_{10} was attributed to unaccounted on-site secondary particle formation.

Case Study 2 results show NO_x annual average maxima of 0.030 ppm, within standards, but daily maxima of 0.12 ppm during temperature inversions. SO_2 averaged 0.010 ppm annually, with hourly peaks of 0.08 ppm. PM_{10} annual average was 60 µg/m³, slightly above the standard. Modeled values generally overpredicted under convective conditions (FAC2 = 0.80, NMSE = 0.35, MB = +0.05). The steel plant's tall stack (120 m) and high exit velocity (20 m/s) facilitated plume lofting, reducing ground-level impacts compared to the petrochemical complex's shorter stacks (60 m) and lower exit velocities (10 m/s).

Statistical Validation

Comparison of modeled vs. observed concentrations at fixed monitors yielded MB values of –0.02 ppm for NO_x and +0.005 ppm for SO_2, indicating slight underprediction of NO_x and marginal overprediction of SO_2. The overall FAC2 for all pollutants averaged 0.78, satisfying EPA performance criteria (FAC2 ≥ 0.5). Correlation coefficients exceeded 0.70 for NO_x and SO_2, and 0.65 for PM_{10}.

CONCLUSION

This assessment demonstrates AERMOD's capability—using 2015-era methodologies—to simulate pollutant dispersion in industrial zones with acceptable accuracy for regulatory screening and impact analysis. Key findings include: (1) taller stacks with higher exit parameters significantly mitigate ground-level concentrations, (2) fugitive PM_{10} emissions require supplementary control measures, as model underprediction underscores secondary particle processes, (3) stable meteorological conditions and low wind speeds exacerbate pollutant accumulation near sources, and (4) robust ambient monitoring is essential for model validation and calibration. For industrial planners and environmental engineers, employing AERMOD in conjunction with detailed source characterization and high-quality meteorological inputs enables informed decisions on stack design, emission control strategies, and community exposure mitigation. Future work—beyond 2015—could integrate advanced sensor networks and chemical transport models to capture secondary formation and complex photochemical reactions, however, within the constraints of pre-2016 technologies, AERMOD remains a sound tool for air quality management in industrial settings.

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