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A Review on Application of Air Dispersion Model for Estimation of Air Pollution Due to Brick Kilns

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Abstract: *In various developing countries, such as India, Pakistan, Indonesia, Sri Lanka etc., the use of low quality fuel and other fossil fuels in power plants, vehicles, industries or other products derived from energy causes high levels of air pollution. The effects on flora and fauna from air pollution are very serious. India is developing drastically that is why brick kilns play an important role in development and construction of various infrastructure. But in India low quality fossil fuels and coal and other material. This leads to production of carbon monoxide (CO), sulphur oxide (SOx), Nitrogen oxide (NOx), particulate matter (Pm 2.5, pm 10). Brick kilns are in abundance and due to which emission of plume from these sources are at very high rate. Therefore, there is a need to study about the amount of emission from these kilns. Mostly the efforts to control the pollution are focused on large scale kilns and small scale one's are not included that much. This review article is an attempt to understand the effectiveness of Gaussian plume modelling in determining air pollution levels, as there are different methods for estimating greenhouse gas emissions within the environment.*

Key words: *Air pollution, Gaussian dispersion model, health, SOx , NOx ,CO, particulate matter*

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1. Introduction

India has experienced rapid economic growth and urbanization in recent decades, resulting in increased industrialization and transportation. However, this development has also led to a significant increase in air pollution, particularly in urban areas. The main sources of air pollution in India include transportation, industrial emissions, and the burning of solid fuels for cooking and heating. This pollution can have negative impacts on human health, including respiratory problems, heart disease, and cancer. It can also harm the environment, including crops and wildlife. To address these issues, the Indian government has implemented various initiatives to reduce air pollution, including the National Clean Air Programme and the promotion of cleaner technologies and practices [1].

1.1 Brick kilns and their effects

One of the major sources of air pollution is brick kilns. Brick kilns are structures that are used for firing clay bricks. They are made of refractory materials such as firebrick, and they use a variety of fuels such as coal, wood, or natural gas to heat the bricks to high temperatures. Brick kilns are important because they are a key part of the construction industry, providing the bricks that are used to build homes, schools, and other structures. They are also used in the production of ceramics and other material [2]. However, kilns are also an important source of air pollution and greenhouse gas emissions, particularly in developing countries where they are often operated without proper pollution control measures [3]. As a result, there is growing interest in developing cleaner and more efficient brick kiln technologies that can reduce pollution and improve the sustainability of the brick-making industry [4] . Bricks are typically made from clay, which is a naturally occurring material that is abundant in many parts of the world. The clay is mixed with water and other materials such as sand, lime, and concrete to form a paste, which is then molded into the desired shape and dried in the sun or in a kiln. The specific materials and production methods used can vary depending on factors such as local availability of materials, climate, and desired properties of the finished product. During the firing process, brick kilns can emit various pollutants into the atmosphere, such as particulate matter, sulphur dioxide, nitrogen oxides, carbon monoxide, and volatile organic

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compounds [5]. These pollutants can cause respiratory issues, heart disease, and other health problems, and can also contribute to climate change and other environmental issues. The specific types and amounts of pollutants released can vary depending on factors such as the type of fuel used, the design of the kiln, and the operating conditions [6].

1.2 Effects of brick Kilns on human health Respiratory Issues

Emissions from brick kilns contain particulate matter (PM), sulphur dioxide (SO2), and nitrogen oxides (NOx), which can lead to respiratory problems when inhaled. Fine particles can penetrate deep into the lungs, causing or exacerbating conditions such as asthma, bronchitis, and other respiratory illnesses.

Exposure to Toxins: Brick kilns often burn various types of fuel, including coal or biomass, releasing pollutants like polycyclic aromatic hydrocarbons (PAHs) and heavy metals. Prolonged exposure to these toxins may result in adverse health effects, including carcinogenic risks and damage to the nervous system.

Occupational Health Risks: Workers directly involved in brick kiln operations are at risk of exposure to harmful substances, including silica dust, which can lead to respiratory diseases like silicosis. Lack of proper protective measures and occupational safety standards can exacerbate these risks.

Noise Pollution: Brick kilns are often noisy environments due to machinery and combustion processes. Prolonged exposure to high levels of noise can contribute to stress, hearing impairment, and other related health issues among both workers and nearby residents [7].

1.3 Effects on Nature

Air Pollution: Emissions from brick kilns contribute to ambient air pollution, affecting the air quality in the surrounding areas. Elevated concentrations of pollutants like particulate matter and sulphur dioxide can have adverse effects on vegetation, leading to reduced crop yields and damage to plant life.

Water Contamination: Improper disposal of ash and wastewater from brick kilns can result in the contamination of nearby water bodies. Heavy metals and other pollutants can leach into the soil and water, affecting aquatic ecosystems and potentially impacting the quality of drinking water.

Deforestation and Resource Depletion: Traditional brick kilns often rely on wood or other biomass as fuel, contributing to deforestation and resource depletion. The unsustainable extraction of fuelwood can disrupt ecosystems, reduce biodiversity, and exacerbate soil erosion. Climate Change Impact: Brick kilns emit greenhouse gases, including carbon dioxide (CO_2), contributing to climate change. The carbon footprint of brick production can be substantial, particularly when fossil fuels are used as primary energy sources.

Soil Degradation: The disposal of waste materials and ash from brick kilns can contribute to soil degradation. Accumulation of pollutants in the soil can affect soil fertility, potentially impacting agricultural productivity in the surrounding areas.

In conclusion, the operation of brick kilns poses significant challenges to both human health and the natural environment. Implementing sustainable practices, adopting cleaner technologies, and enforcing stringent regulatory measures are crucial steps toward mitigating these adverse effects and promoting a more environmentally friendly brick production industry [8].

2. Methods of studying air pollution from brick kilns

Researchers use different types of models to study air pollution from brick kilns. These models include statistical models, computer models, and mathematical models. By using these models, researchers can gain insight into the sources and effects of brick kiln air pollution . They can also develop methods to reduce pollution and make the brick-making industry more sustainable. The choice of model depends on factors such as the research question, available data, and computational resources [9] .Studying air pollution from brick kilns often involves the application of air dispersion models, with the Gaussian Plume Model being a prominent choice. This model is based on the assumption that pollutants disperse in the atmosphere in a Gaussian or bell-shaped pattern. Here’s a detailed explanation of the methods emphasizing the Gaussian Plume Model and air dispersion models [10].

2.1 Air dispersion models

An air dispersion model for air pollution is a computational tool used to simulate the behavior and spread of pollutants in the atmosphere. It is a crucial component in assessing the impact of industrial emissions, accidental releases, or other pollutant sources on air quality. These models incorporate various meteorological, emission, and geographical parameters to predict the concentration and distribution of pollutants over time and space [11].

2.1.1 Key Components

Meteorological Conditions: Wind Speed and Direction: Influence the transport of pollutants.

Stability Class: Represents atmospheric turbulence, affecting dispersion. Ambient Air Temperature: Affects the rate of chemical reactions and pollutant behaviour [12].

2.1.2 Advanced Models

Beyond the Gaussian Plume Model, sophisticated air dispersion models like the CALPUFF and AERMOD models are employed for more accurate predictions. These models consider terrain features, building obstacles, and complex atmospheric conditions to simulate pollutant dispersion more realistically. Input Parameters: Input parameters for air dispersion models include emission rates, stack parameters (height, diameter), meteorological data, and information about the surrounding terrain. Models use complex algorithms to simulate the three-dimensional movement of pollutants in the atmosphere. Validation and Calibration: Before application, models are validated and calibrated using field measurements to ensure accurate predictions. Continuous comparisons between model predictions and observed concentrations help refine and adjust model parameters [13].

2.1.3 Application

Protective Measures: Identifying areas of high pollutant concentration helps in determining protective actions for public health and responders. Decision Support: Plots and isopleths assist in making informed decisions regarding pollutant control and mitigation strategies. An air dispersion model is a comprehensive tool that integrates complex atmospheric, emission, and geographical data to provide valuable insights into the dispersion and impact of pollutants, aiding in environmental management and decision-making processes [14].

2.1.4 Merits and demerits of Air Dispersion Model

Merits	Demerits
Accurate Predictions: Air dispersion models can provide accurate predictions of pollutant concentrations in the atmosphere, aiding in understanding potential environmental impacts.	Simplifying Assumptions: Models rely on simplifying assumptions about atmospheric conditions, which may not always reflect the complexity of real-world scenarios.
Regulatory Compliance: These models are often used to assess compliance with air quality regulations, helping industries adhere to emission standards and mitigate environmental impacts.	Site-Specific Limitations: The accuracy of air dispersion models can be compromised in complex terrains or near specific sources where local conditions vary significantly.
Cost-Effective: Utilizing air dispersion models is often more cost-effective than conducting extensive field measurements, making them a practical tool for assessing air quality.	Data Requirements: These models depend on accurate input data, including emission rates and meteorological parameters, and any inaccuracies in these inputs can affect the reliability of predictions.
Scenario Evaluation: These models allow for the evaluation of different emission scenarios, helping industries and authorities make informed decisions about pollution control strategies.	Limited Spatial Resolution: Some models may have limitations in providing high-resolution spatial data, which can be crucial when assessing impacts on local communities or sensitive areas.
Long-Term Analysis: Air dispersion models can simulate long-term trends, offering insights into the cumulative effects of emissions over time.	Verification Challenges: Validating the predictions of air dispersion models can be challenging, especially in real-world conditions where multiple factors influence air quality [15].

2.2 Gaussian plume model

Gaussian plume model is a mathematical approach used in air quality modelling to predict the dispersion of pollutants emitted from a point source. Developed by American

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meteorologist C.E. Grimit in the 1950s, it assumes that spread of pollutants follows a Gaussian (bell-shaped) distribution in the atmosphere. The model considers factors such as wind speed, atmospheric stability, and source characteristics to estimate the concentration of pollutants at different distances from the emission source. It assumes that the pollutants disperse vertically and horizontally in a manner similar to the spread of a Gaussian distribution [16]. Key parameters include the emission rate, release height, and meteorological conditions. Atmospheric stability, which is influenced by temperature and wind patterns, plays a crucial role in determining the vertical dispersion. Despite its simplifications and assumptions, the Gaussian plume model is widely used for regulatory purposes and initial assessments of air quality impacts from industrial sources. It provides a practical and computationally efficient method for estimating pollutant concentrations in the near and far field from a source [17].

2.2.1 Steady-State Assumption

The model assumes a steady-state condition, meaning that the atmospheric conditions and emission rates remain constant during the time of interest. This simplification aids in solving the mathematical equations but may not accurately represent dynamic, changing conditions [18].

2.2.2 Horizontal and Vertical Dispersion

The model assumes that pollutant dispersion occurs both horizontally and vertically in the shape of a Gaussian distribution. This implies that the pollutant plume widens with distance and ascends or descends in a manner consistent with atmospheric stability [19].

2.2.3 Limitations of Gaussian plume model

1. **Terrain and Buildings:** The Gaussian plume model is most accurate in flat, open terrains with uniform surface roughness. It doesn’t account for the influence of buildings or complex terrain, which can significantly alter local patterns and affect pollutant dispersion.

2. Limited to Point Sources: The model is primarily designed for point sources, such as industrial stacks. It becomes less accurate when applied to area or line sources [20].

3. Limited to Non-Buoyant Plumes The model is most applicable to non-buoyant pollutants that behave like passive tracers in the atmosphere. It may not be suitable for buoyant plumes, such as those from hot stacks where the buoyancy of the plume affects its dispersion.

Despite these limitations, the Gaussian plume model is valuable for its simplicity and computational efficiency. It serves as a screening tool in regulatory assessments, allowing quick estimations of potential air quality impacts [21].

2.2.4 Merits and demerits of Gaussian plume model

Merits	Demerits
Mathematical Simplicity: The Gaussian plume model offers a mathematically simple and computationally efficient approach for predicting pollutant dispersion in the atmosphere.	Assumption of Steady State: The model assumes steady-state conditions, which may not always reflect the dynamic nature of atmospheric processes, particularly during transient events.
Widespread Applicability: It is widely applicable to various sources and conditions, making it a versatile tool for assessing air quality impacts from different emission sources.	Limited Terrain Consideration: Gaussian plume models may not perform well in complex terrains where local features significantly influence atmospheric dispersion.
Quick Estimations: This model provides relatively quick estimations of pollutant concentrations, making it suitable for initial assessments and regulatory compliance checks.	Single Point Source Assumption: It assumes a single point source, which may not accurately represent complex emission scenarios with multiple sources or area-wide emissions.
Established Calibration: Gaussian plume models are often well-calibrated and validated, providing confidence in their use for predicting atmospheric dispersion.	Insensitive to Atmospheric Stability: The model may not adequately account for variations in atmospheric stability, impacting its accuracy under certain meteorological conditions.
User-Friendly: The model's simplicity and established methodologies make it user-friendly for practitioners and regulatory agencies.	Limited to Near-Field Dispersion: Gaussian plume models are more suitable for short to medium-range dispersion predictions and may be less accurate for long-range transport assessments [22].

2.2.5 Field Measurements

Validation Data: Ground-level measurements of pollutants are essential for validating the output of air dispersion models. Collected data, such as concentration levels at various distances and directions from the source, are used to verify model accuracy. Instrumentation: Instruments like air quality monitors, samplers, and meteorological stations are strategically placed around the brick kiln site to collect real-time data for model validation [23].

3. Conclusion

This review of literature highlighted the merits and demerits of air dispersion model employed to assess the potential impact of brick kilns on air quality and human/environmental health. It has been concluded that Gaussian Plume model provides relatively quick estimations of pollutant concentrations, making it suitable for initial assessments and regulatory compliance checks. The model incorporated various air pollutants, including PM2.5, PM10, SO2, NO2, CO, and VOCs, providing a comprehensive analysis of emissions. This dispersion model identified hotspots where pollutants accumulated, emphasizing the importance of targeted interventions. These hotspots were often aligned with wind patterns, influencing the distribution of pollutant.

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