SETTING UP AERMOD DISPERSION MODEL IN PAKISTAN: A CASE STUDY OF BRICK KILN IN ISLAMABAD

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Dedication

This research is dedicated to my loving, caring, and industrious parents, my sister and Dr. Maham Rizwan whose efforts and sacrifice have made my dream of having this degree a reality. words cannot adequately express my deep gratitude to them.
"O My Sustainer, Bestow on my parents your mercy even as they cherished me in my childhood".

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Contents

List of Abbreviation or Keywords

AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
PM	Particulate Matter
CO	Carbon Monoxide
CO_2	Carbon Dioxide
SO_2	Sulphur Dioxide
GIS	Geographic Information System
EPA	Environmental Protection Agency
AMS	American Meteorological Society
AERMET	Meteorological Data Preprocessor for AERMOD
PBL	Planetary Boundary Layer
ABL	Atmospheric Boundary Layer
DEM	Digital Elevation Model
PRIME	Plume Rise Model Enhancements
TSP	Total Suspended Particles
PMF	Positive Matrix Factorization
CMB	Chemical Mass Balance

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ABSRACT

The use of brick kilns is a significant source of air pollution in Pakistan, especially in urban areas. The AERMOD dispersion model has been widely used to evaluate the air quality impacts of brick kilns in Pakistan. This literature review summarizes the findings of various studies that have applied the AERMOD model to evaluate the impacts of brick kilns in Pakistan. The review highlights the effectiveness of the AERMOD model in predicting air pollution concentrations and identifying the major sources of pollution from brick kilns. Several studies found that brick kilns are a significant source of particulate matter emissions and recommended the use of cleaner technologies to reduce emissions. The AERMOD model has also been used to evaluate the health and environmental impacts of air pollution from brick kilns. Studies found that air pollution from brick kilns was associated with increased mortality, morbidity, and reduced tree growth. The AERMOD model has several advantages over other air quality models when evaluating the impacts of brick kilns in Pakistan. The model considers the effects of terrain and buildings on the dispersion of pollutants, which can improve the accuracy of the predictions. Moreover, the model can simulate multiple sources of pollution simultaneously, which is essential when evaluating the impacts of brick kilns in urban areas. However, the AERMOD model also has some limitations when evaluating the impacts of brick kilns in Pakistan. The model requires accurate input data, which may be scarce or of poor quality in some regions, limiting the accuracy of the model. The AERMOD dispersion model is a valuable tool for evaluating the air quality impacts of brick kilns in Pakistan. The findings of this review suggest the importance of implementing better pollution control measures and using cleaner technologies to reduce emissions from brick kilns in Pakistan. In this study the model has been utilized to develop an understanding of the plume distribution from a brick kiln in Islamabad. Moreover, an attempt has been made to cover the shortcomings in data inputs which are not applicable for the model in the country.

CHAPTER 1

1. INTRODUCTION

The issue of air quality has gained significant global attention due to its impact on human health and the natural environment. Consequently, studying atmospheric conditions is crucial in effectively tackling this problem. The comprehension of pollutant dispersion and risk assessment may be enhanced by using air quality models. The need for effective air quality management must be addressed in light of Pakistan's significant air pollution problem.

1.1. Background of the study

The Earth's atmosphere primarily consists of Oxygen (O_2), carbon dioxide (CO_2), and nitrogen (N_2) as well as other gases such as Ozone (O_3), Methane (CH_4), and water vapour (H_2O). The Earth's atmosphere harbors essential gases conducive to sustaining life; nevertheless, it is susceptible to pollution from natural phenomena and human activities (Afzali *et al.,* 2017).

1.1.1. Natural and anthropogenic sources of air pollution

The list of naturally occurring causes of air pollution is long, but includes things like volcanoes, dust storms, wildfires, and biological emissions. A wide variety of materials, including gases, ash, and particles, are released into the air during volcanic eruptions. During volcanic eruptions, SO_2 is released into the atmosphere, which may cause acid rain and localized air pollution. Large quantities of dust particles carried by dust storms are detrimental to air quality. Smoke, PM, CO, and VOCs are only some of the air pollutants produced by wildfires. Reduced air quality due to the presence of these pollutants might cause health problems and impaired vision. Plants, trees, and microbes may all emit biological emissions into the air, such as pollen, spores, and BVOCs, which can lead to a localized decrease in air quality (Afzali et al., 2014).

Human activities are likely the main cause of air pollution. Industrialization, electricity production, transportation, home and commercial usage, and agricultural practices are all human-caused factors that contribute to global warming. Some of the various air pollutants created by industry are sulfur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM), and volatile organic compounds (VOCs). When fossil fuels are used for purposes, such as generating electricity or powering factories, pollutants are released into the atmosphere. Sulphur dioxide (SO2) emissions are significantly impacted by coal-fired power plants. Nitrogen oxides (NOx), carbon monoxide (CO), and particulate matter (PM) emissions are worsened by transportation, especially petrol and diesel-powered cars. One possible cause of rising pollution levels is the widespread use of solid fuels like wood and coal for domestic and industrial cooking and heating. Agricultural practices, such as animal husbandry and the use of fertilizers, may contribute to atmospheric pollution by releasing ammonia (NH3) and other pollutants (Al-Zhoon *et al.,* 2022).

1.1.2. Meteorological factors affecting air quality

Meteorological conditions significantly impact the dispersion and transportation of air pollutants. The weather affects the air movement, dilution, and concentration of pollutants.

Temperature

Elevated temperatures can alter the physical and chemical properties of pollutants. Ground-level ozone (O3) production might potentially increase at elevated temperatures due to photochemical reactions. The evaporation rates of volatile organic compounds (VOCs) can increase when temperatures rise, leading to elevated concentrations of secondary pollutants, such as ozone. The potential for air pollution problems may be heightened by temperature inversions, which occur when a layer of warm air restricts the vertical dispersion of pollutants and retains cooler air near the surface. This phenomenon leads to the accumulation of pollutants in areas characterized by limited air circulation (Snoun, *et al.,* 2023).

Wind Speed and Direction

Wind velocity and orientation significantly impact the dispersion and transportation of pollutants. Higher wind speeds facilitate the dilution and dispersion of pollutants, reducing concentrations in localised areas. The spatial dispersion of atmospheric pollution is affected by the prevailing wind patterns since they determine the ease with which pollutants may be delivered from their sources to their respective target locations. The air quality in downwind regions may be adversely affected due to the transportation of toxins by prevailing winds (Touma *et al.,* 2007).

Atmospheric Stability

Wind velocity and orientation significantly impact the dispersion and transportation of pollutants. Higher wind speeds facilitate the dilution and dispersion of pollutants, reducing concentrations in localized areas. The spatial dispersion of atmospheric pollution is affected by the prevailing wind patterns since they determine the ease with which pollutants may be delivered from their sources to their respective target locations. The air quality in downwind regions may be adversely affected due to the transportation of toxins by prevailing winds (Perillo *et al.,* 2022).

Precipitation

The wet deposition process, which involves the deposition of contaminants from the atmosphere via precipitation, such as rain or snow, serves as an effective mechanism for removing pollutants and contributes to the preservation of environmental cleanliness. Raindrops effectively eliminate particulate matter and soluble gases from the atmosphere. Airborne pollutants have the potential to be eliminated by precipitation, thus leading to their deposition on the Earth's surface. According to Matacchiera et al. (2019), certain pollutants may lead to chemical reactions with rainfall, resulting in secondary pollutants such as acid rain.

In contrast to temperature, wind speed, atmospheric stability, and precipitation, the influence of atmospheric pressure, humidity, and solar radiation on air quality is comparatively less. To achieve precise air quality modelling and assessment, it is important to possess a comprehensive understanding of the interplay between meteorological conditions and atmospheric pollutants.

The impact of atmospheric composition and meteorological conditions on air quality might vary based on geographical location, seasonal variations, and local emission sources. Therefore, it is important to undertake comprehensive monitoring and analysis of these factors to appreciate and address unique air pollution concerns in different locations (Langner & Klemm, 2011).

1.2. Air quality modelling

Air quality modelling plays a crucial role in environmental research as it provides valuable insights into air pollutants' dispersion, transport, and chemical transformation throughout the atmosphere. In order to enhance understanding of the sources, dispersion patterns, and potential impacts of contaminants on human health and the ecosystem, these models use mathematical and scientific principles to replicate their behaviour. This article examines the use of air quality models in research and provides an overview of the many currently available models (Kumar *et al.,* 2006).

1.2.1. Role of Air Quality Models in Environmental Studies

Air quality models are essential for accurate assessment and management of air pollution. These tools help scientists, policymakers, and environmentalists make sense of the interconnected web of emissions, climate, and pollution impacts. They are also helpful for learning about the intricate mechanisms that lead to pollution spreading. Possible applications of these models include air quality predictions, policy evaluation, and the development and implementation of anti-pollution initiatives (Muddassir *et al.,* 2023).

Air quality models are crucial to environmental science because of their widespread practical use. Pollutant concentration forecasts and health effects evaluations are two uses for air quality models. The models above incorporate emission inventories, meteorological data, and pollutant transformation algorithms to forecast levels of pollutants at designated receptor sites, which can then be used to assess compliance with air quality regulations and improve understanding of exposure patterns (Minabi et al., 2017).

Many different emission sources may contribute to air pollution, and these sources can be identified with high accuracy using air quality models. Source apportionment methods like chemical mass balance and positive matrix factorization may efficiently include pollution sources like factories, cars, and open fires into models. The collection of this information is essential for the development of efficient strategies to reduce pollution (Khan *et al.,* 2022).

Air quality models are invaluable tools when evaluating the success of laws and regulations meant to reduce air pollution. Using models, one may simulate various policy scenarios to estimate the potential for changes in air quality and evaluate the accompanying health and environmental benefits. Possible outcomes include adopting emission-cutting measures or altering current land-use patterns. This allows government agencies to better analyse the situation and provide resources to reduce pollution.

Emergency response planning in times of high pollution or reaction to catastrophes like industrial accidents or wildfires may benefit from the information provided by air quality models. By modelling pollutant dispersion and movement, these models can estimate the possible effect on neighbouring populations, aid in creating evacuation plans, and assist decision-making processes to limit exposure risks (O'Shaughnessy & Altmaier, 2011).

1.2.2. Types of Air Quality Models

Several air quality models are available, each designed to address certain inquiries or fulfil distinct objectives. The complexity of these models and the pollutants and processes they separate facilitate valuable classification. Several commonly used types of air quality models include the following:

Dispersion Models

Air pollution dispersion models simulate the transport of harmful gases from their sources to specific locations in the surrounding environment. These models use data inputs, including emission rates, meteorological conditions, geographical factors, and atmospheric stability, to forecast pollutant concentrations at specific places. The AERMOD dispersion model is often used for regulatory purposes due to its ability to simulate complex meteorological conditions and the effects of terrain accurately (Jittra *et al.,* 2015).

Photochemical Models

The synthesis and transformation of secondary pollutants, such as ozone (O3) and particulate matter, have particular significance in the context of photochemical models. In order to replicate the origins of pollutants in diverse ecosystems, these models include factors such as solar radiation, ambient temperature, and the presence of precursor substances. The comprehension of ozone formation mechanisms and the identification of efficient management strategies may be achieved via the use of photochemical models (Kalhor & Bajoghli, 2017).

Source Apportionment Models

Source apportionment models may be used to disaggregate pollutant concentrations into distinct contributions from different emission sources. These models use data obtained from air quality monitoring stations and statistical methodologies to approximate the amount of pollution attributed to certain sources. To assess the proportional impacts of various emission sources, such as industrial operations, vehicular discharges, and residential combustion, source apportionment models such as the Chemical Mass Balance (CMB) model and the Positive Matrix Factorization (PMF) model are employed. These models gauge pollutant concentrations and source profiles to estimate the respective contributions of each emission source (Balter & Faminskaya, 2017).

Regional-Scale Models

Regional-scale models simulate and analyze air quality patterns over extensive geographical areas, considering the intricate process of pollution movement across various regions. These models include regional emission inventories, climatic data, and the interplay between local and long-range pollution transport. Regional-scale models play a crucial role in assessing air quality trends on a greater scale, evaluating regional pollution control methods, and comprehending the damage caused by the movement of pollutants from distant sources (Atabi *et al.,* 2014).

Indoor Air Quality Models

The main emphasis of indoor air quality models is assessing pollutant concentrations in buildings and other confined areas. When assessing the levels of indoor air pollution, these models include factors such as the ventilation system of the building, emission rates of interior sources (such as cooking and cleaning chemicals), and the residents' behaviors. Using indoor air quality models may significantly enhance the assessment of exposure dangers and the advancement of effective ventilation and filtration systems.

The selection of an appropriate air quality model should be based on many factors, including the specific objectives of the research, the availability of relevant data, the computational capabilities of the computer system, and the required level of precision and comprehensiveness. Using many models in conjunction is a common practice in elucidating the intricate dynamics of air pollution (Hanna *et al.,* 2007).

1.3. AERMOD dispersion model

The American Meteorological Society and the Environmental Protection Agency's AERMOD dispersion model is widely used for assessing air quality and formulating regulations. The system's goal is to analyze how pollution from factories travels and spreads into the atmosphere. In this section, we provide a high-level summary of AERMOD's development and history, focusing on its core features and individual parts.

1.3.1. Development and Evolution of AERMOD

The AERMOD model originated from the Industrial Source Complex (ISC) model, which gained significant popularity during the 1980s due to its extensive use in regulatory contexts. The ISC model represented a notable advancement compared to preceding techniques in forecasting pollutant concentrations originating from high-point sources since it used established Gaussian plume equations. Nevertheless, in response to the increasing need for more precise and rigorous modeling capabilities, the EPA and AMS joined together to create AERMOD. The development of AERMOD began in the late 1990s, aiming to improve the ISC model by incorporating state-of-the-art scientific discoveries and computational methodologies. (Hanna *et al.,* 2001; Radford *et al.,* 2021).

The key objectives in the development of AERMOD were:

- Improved Representation of Atmospheric Conditions: AERMOD aimed to better represent the complexities of atmospheric conditions, including variations in terrain, stability, and meteorological parameters. The model incorporated advanced techniques to handle complex terrain features, such as hills, valleys, and coastlines, which can significantly influence the dispersion patterns of pollutants.

- Enhanced Dispersion Algorithms: AERMOD introduced updated dispersion algorithms that were based on a combination of Gaussian and plume-in-grid techniques. These algorithms improved the accuracy and reliability of pollutant concentration estimates by considering the effects of both near-field and far-field dispersion.
- Incorporation of Advanced Meteorological Data Processing: AERMOD utilized advanced meteorological data processing techniques to enhance the representation of atmospheric conditions. The model integrated surface and upper-air meteorological data, such as wind speed, wind direction, temperature, and atmospheric stability, to provide more realistic simulations of pollutant dispersion.
- Consideration of Multiple Source and Receptor Configurations: AERMOD was designed to handle multiple source and receptor configurations, allowing for a more comprehensive assessment of air quality impacts. The model accounted for multiple point, area, and volume sources, as well as multiple receptors located at different heights and distances from the sources.

Over the years, AERMOD has undergone several updates and refinements to incorporate new scientific findings, advancements in computational capabilities, and user feedback. These updates have resulted in improved model performance, enhanced features, and increased usability for air quality practitioners (Cimorelli *et al.,* 2005; Rani *et al.,* 2021).

1.3.2. Key Features and Components of AERMOD

The AERMOD dispersion model comprises several key features and components that contribute to its accuracy and reliability in simulating pollutant dispersion. Some of the key features and components include:

a) Treatment of Terrain and Land Use Characteristics: AERMOD incorporates detailed terrain data, such as elevation, slope, and roughness length, to account for the influence of topography on pollutant dispersion. It also considers land use characteristics, such as urban areas or vegetation, which can affect atmospheric turbulence and pollutant dispersion patterns.

b) Atmospheric Stability Classifications: AERMOD classifies atmospheric stability into different categories, such as stable, neutral, or unstable, based on the vertical temperature gradient. These stability classifications are critical in determining the vertical mixing and dispersion of pollutants. AERMOD incorporates stability-specific algorithms to estimate the dispersion parameters accordingly.

c) Vertical and Lateral Dispersion Algorithms: AERMOD employs advanced algorithms to estimate vertical and lateral dispersion. Vertical dispersion accounts for the spread of pollutants in the vertical direction due to atmospheric turbulence and eddy diffusion. Lateral dispersion considers the lateral spread of pollutants perpendicular to the wind direction due to turbulence and atmospheric processes. AERMOD incorporates algorithms that consider the effects of plume rise, near-field dispersion, and far-field dispersion to accurately estimate pollutant concentrations at receptor locations.

d) Treatment of Meteorological Data: AERMOD utilizes meteorological data, such as temperature, wind direction, wind speed, and atmospheric stability, to simulate pollutant dispersion. The model provides options to input site-specific meteorological data or use data from nearby meteorological stations. It also incorporates algorithms to handle missing or incomplete data, ensuring robust simulations even with limited meteorological information.

e) Multiple Source and Receptor Configurations: AERMOD allows for the consideration of multiple source and receptor configurations, providing flexibility in assessing air quality impacts. It can simulate emissions from point sources (e.g., stacks), area sources (e.g., industrial facilities), and volume sources (e.g., traffic emissions). Multiple receptors located at different heights and distances from the sources can be included to evaluate pollutant concentrations at various locations of interest.

f) Model Output and Visualization: AERMOD generates output files that provide information on pollutant concentrations, plume characteristics, and model performance statistics. The model output can be visualized using graphical tools or Geographic Information System (GIS) software to facilitate data analysis and interpretation. Visualization tools help identify areas of potential concern and aid in communicating model results to stakeholders.

g) Regulatory Compliance: AERMOD is widely accepted for regulatory applications and meets the requirements of various air quality regulations, including those set by the Environmental Protection Agency (EPA). The model incorporates the necessary features and methodologies to assist in compliance with air quality standards and permit requirements.

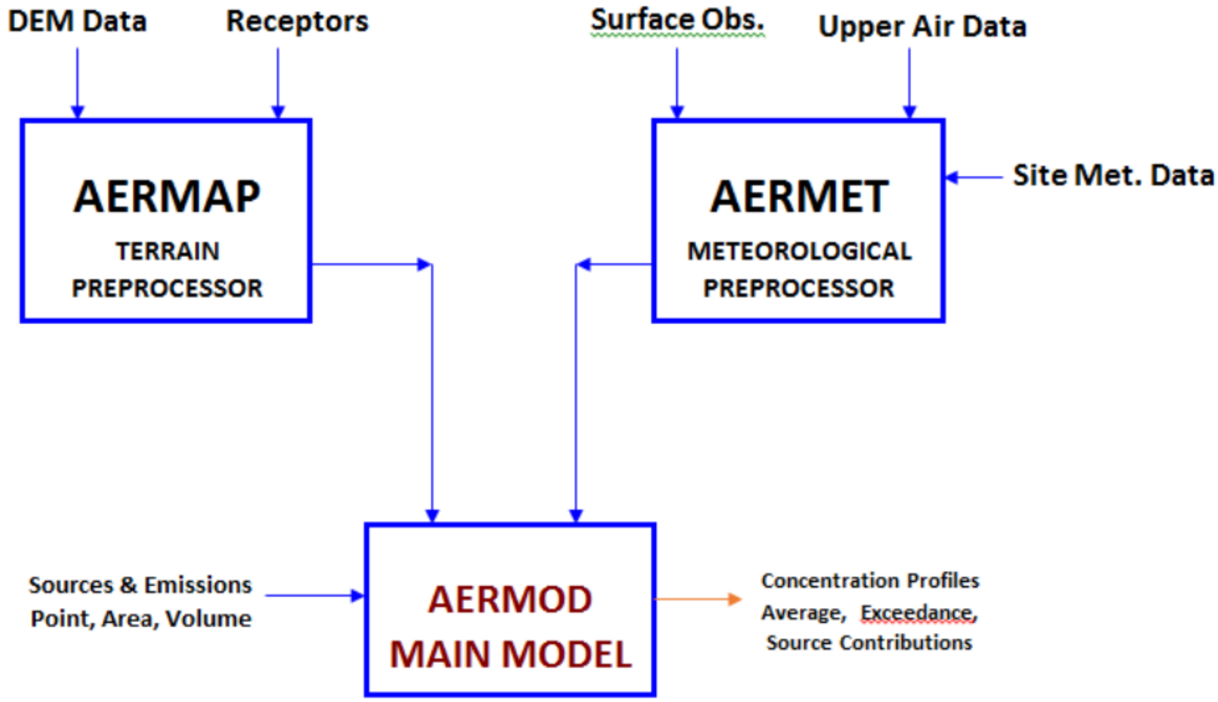


Figure 1-1AERMOD modelling system (Mahsa et al., 2018)

The continuous development and refinement of AERMOD has contributed to its widespread use in air quality assessments and regulatory applications. Its advanced features, including the treatment of terrain, incorporation of atmospheric stability classifications, utilization of meteorological data, consideration of multiple source and receptor configurations, and compliance with regulatory standards, make it a valuable tool for simulating and predicting pollutant dispersion (Faulkner *et al.,* 2008).

1.4. Objectives of the Study

To fulfil the requirements, following objectives are considered in this work:

- Exploring the optimal settings of AERMOD in Pakistan's conditions
- Estimating the spatial and temporal emissions profile of an industrial unit by using AERMOD

CHAPTER 2

2. LITERATURE REVIEW

The AERMOD dispersion model may be used to forecast air pollution levels in urban areas around the globe. This model has been widely used in several studies investigating air quality and the impacts of various sources of pollution. Numerous worldwide studies have shown the efficacy of the AERMOD model in properly estimating air pollution concentrations and discerning the primary sources of pollution.

Zou et al. (2010) conducted an analysis using the AERMOD model to assess the impact of an Irish biomass power plant on the quality of air. Based on the study's findings, the model effectively made accurate predictions about the levels of air pollution, identifying the power plant as a significant source of the issue.

In their study, Tartakovsky et al. (2013) used the AERMOD model to evaluate the impact of transport emissions on the air quality of Shanghai, China. According to the study, the model demonstrated a high level of accuracy in simulating the dispersion of pollutants and effectively identifying significant sources of pollution.

Shojaee Barjoee et al. (2019) used the AERMOD model to assess the impact of shipping emissions on the air quality within the Yangtze River Delta region in China. The study findings indicate that the model effectively forecasted air pollution levels, with a notable emphasis on the significant role played by ship emissions in exacerbating the issue.

The assessment of the impact of air pollution on human health has also been conducted via the use of the AERMOD model. Ma et al. (2013) used the AERMOD model to evaluate the hazards associated with air pollution in Beijing, China. The study identified transportation emissions as the predominant source of air pollution, which was shown to be associated with increased death and morbidity rates.

The assessment of air pollution's impact on ecosystems has also been conducted using the AERMOD model. Pandey and Sharan (2021) used the AERMOD model to evaluate the impact of air pollution on a forest ecosystem in Iran. The study's findings indicated that air pollution and its associated decrease in tree growth were mostly attributed to vehicle emissions.

AERMOD demonstrates superiority over other air quality models in many aspects. Compared to previous models, such as ISCST3 and CALINE4, the current model employs a more intricate methodology for modeling air dispersion. The AERMOD model is capable of generating precise predictions by considering the influence of geographical factors and structures on the dispersion of pollutants. Furthermore, the model can replicate many pollution sources simultaneously, a crucial attribute in urban areas characterized by a dense concentration of pollution sources (Perry et al., 2005).

Nevertheless, the AERMOD paradigm is not exempt from its inherent limitations. Accurate meteorological, land use and emission inventory data are essential prerequisites for the model. The availability and quality of these data could be more robust in some regions, potentially leading to a decrease in the model's accuracy. Furthermore, it should be noted that the model operates on the assumption of pollutant homogeneity, which may only sometimes hold (Olesen et al., 2011).

Extensive research has been conducted on the ramifications of air quality resulting from brick kilns using the AERMOD dispersion model. Brick kilns in economically disadvantaged countries, often located in close proximity to residential areas, significantly contribute to air pollution. The AERMOD model can forecast air pollution levels, enabling the identification of significant pollution sources such as brick kilns (Petersen et al., 2017).

Siddique et al. (2016) used the AERMOD model to evaluate the impact of brick kilns on air quality in the Lahore region of Pakistan. The study's findings indicated that brick kilns substantially contributed to local air pollution, prompting a recommendation to transition to cleaner fuels to mitigate emissions.

The study done by Kumar et al. (2006) investigated the impact of brick kilns on air quality in India's National Capital Region using the AERMOD model. Based on the findings of the study, it has been shown that brick kilns play a substantial role in the emission of particulate matter (PM). Consequently, there is a strong need to promote cleaner technologies within the brick kiln sector.

Karim et al. (2020) used the AERMOD model to evaluate the impact of brick kilns on air quality within the Beijing-Tianjin-Hebei region of China. The study's findings indicated that brick kilns generated a significant quantity of particulate matter (PM), emphasizing the need for the use of cleaner fuels and advanced technologies to mitigate emissions.

The AERMOD model has been used to examine the air pollution caused by brick kilns. In their study, Hossain et al. (2020) used the AERMOD model to evaluate the potential health hazards associated with brick kilns in Kolkata, India. The study's findings revealed that the mortality and morbidity rates in the most vulnerable demographic grouping were greater than anticipated, mostly attributed to the exposure to air pollution from brick kilns.

The environmental impacts of brick kilns have also been evaluated using the AERMOD model. Heckel and LeMasters (2011) used the AERMOD model to evaluate the impact of brick kilns in the Yangtze River Delta region of China on water quality and soil. The study's findings indicated that brick kilns substantially contributed to the presence of heavy metals in the environment, highlighting the need for more stringent pollution control measures.

When evaluating air quality models to measure the impacts of brick kilns, the AERMOD model offers many advantages. In order to enhance the accuracy of predictions, the model incorporates the influence of geographical factors and architectural structures on the dissemination of pollutants. The essential aspect in evaluating the impacts of brick kilns in urban areas is the model's capacity to effectively replicate many sources of pollution simultaneously (Guttikunda et al., 2019).

Nevertheless, it is important to acknowledge several limitations when using the AERMOD model to evaluate brick kilns' impacts. Accurate meteorological, land use and emission inventory data are essential prerequisites for the model. There needs to be more or substandard data in certain regions to ensure the model's accuracy. The model also assumes that pollutants are evenly distributed, which may not necessarily be the case in practical situations (Hall et al., 2000).

Numerous research investigations conducted in Pakistan have used the AERMOD dispersion model to assess atmospheric conditions and evaluate the impacts of pollution. The AERMOD model has shown exceptional performance in air pollution concentration forecasts and source identification, as evidenced by the study conducted by Gulia et al. (2015).

In their study, improve et al. (2023) used the AERMOD model to evaluate the impact of industrial emissions on air quality in Lahore, Pakistan. The study's findings indicate that the AERMOD model demonstrated high accuracy in predicting air pollution concentrations. Moreover, the research identified industrial activities as the predominant source of air pollution within the studied region.

The study by Afzal et al. (2017) aimed to evaluate the impact of vehicle emissions on air quality in Rawalpindi, Pakistan, using the AERMOD model. Based on the findings, it can be concluded that the AERMOD model effectively replicated the dispersion of pollutants, with vehicle emissions identified as a significant factor in the prevalence of air pollution in metropolitan areas.

The study by Askariyeh et al. (2017) investigated the impact of brick kilns on air quality in the Gujranwala region of Pakistan. The researchers used the AERMOD model to analyze these impacts. The study revealed that brick kilns emerged as a significant source of air pollution in the region, and the efficacy of the AERMOD model in accurately forecasting pollution levels was shown.

The AERMOD model has been used to examine air pollution in Pakistan due to its perceived risks to human health. In their study, Ul Haq et al. (2019) used the AERMOD model to evaluate the impact of air pollution on public health in Karachi, Pakistan. The study's findings indicated that vehicle emissions substantially exacerbated air pollution, which exhibited a positive correlation with heightened hospital admissions for respiratory and cardiovascular ailments.

Furthermore, an evaluation has been conducted on the impact of air pollution on ecosystems in Pakistan using the AERMOD model. Shaikh et al. (2020) assessed the impact of air pollution on a forest ecosystem in the Murree hills of Pakistan. The AERMOD model was used for this purpose. The study's findings indicated that air pollution and its associated reduction in tree growth were mostly attributed to vehicle emissions.

Compared to other air quality models, the AERMOD model demonstrates superior accuracy in evaluating air quality conditions within Pakistan. In order to enhance the accuracy of the predictions, the model incorporates the influence of geographical factors and architectural structures on the dissemination of pollutants. Furthermore, the model can simulate many pollution sources concurrently, a particularly crucial feature in urban areas characterized by a dense aggregation of pollution sources (Radford et al., 2021).

Nevertheless, it is crucial to consider the AERMOD model's notable limitations while evaluating Pakistan's air quality. Accurate meteorological, land use and emission inventory data are essential prerequisites for the model. The availability and quality of these data could be more robust in some regions, potentially leading to a decrease in the model's accuracy. The validity of this model is contingent upon the underlying assumption of pollutants being uniformly distributed, a condition that may not always hold (Hallaji et al., 2023).

The urban regions of Pakistan have a significant level of air pollution, mostly attributed to the presence of brick kilns. Numerous research investigations conducted in Pakistan have used the

AERMOD dispersion model to evaluate the impact of brick kilns on atmospheric conditions. The study conducted by Naghdi et al. (2023) revealed that the studies conducted effectively assessed the predictive capabilities of the AERMOD model in estimating air pollution concentrations. Furthermore, the study successfully identified the primary sources of pollution originating from brick kilns.

The study undertaken by Karim et al. (2020) focused on the Lahore region in Pakistan, using the AERMOD model to evaluate the impact of brick kilns on atmospheric conditions. The study's findings indicated that brick kilns substantially contributed to local air pollution, prompting a recommendation to transition to cleaner fuels to mitigate emissions.

The study by Afzali et al. (2017) used the AERMOD model to evaluate the impact of brick kilns on air quality in the Mian Channu area of Pakistan. Based on the findings of the study, it has been shown that brick kilns have a substantial role in the emission of particulate matter (PM). Consequently, there is a strong recommendation to promote the use of cleaner technologies within the brick kiln sector.

Amoatey et al. (2019) used the AERMOD model to evaluate the impact of brick kilns on air quality in the Gujranwala area of Pakistan. The inquiry findings prompted the suggestion of improved pollution management strategies since it was shown that brick kilns had a significant role in local air pollution.

The AERMOD model has been used to investigate the air pollution caused by brick kilns in Pakistan. Pakistan and Kolkata, India, have comparable environmental and meteorological conditions. In their study, Guttikunda et al. (2019) used the AERMOD model to examine the health consequences associated with brick kilns in both regions. The study's findings revealed that the mortality and morbidity rates in the most vulnerable demographic grouping exceeded the anticipated levels, mostly attributed to the exposure to air pollution emanating from brick kilns.

The AERMOD model has been used for the evaluation of the environmental impacts caused by brick kilns in Pakistan. In their study, Iyyappan and Kumaravel (2020) used the AERMOD model to evaluate the impact of air pollution from brick kilns on a forest ecosystem located in the Murree hills of Pakistan. The study established a correlation between air pollution from brick kilns and impaired growth of trees while identifying vehicle emissions as a significant factor influencing pollution levels.

When doing a comparative analysis of air quality models for evaluating the impacts of brick kilns in Pakistan, it becomes evident that the AERMOD model has notable advantages. In order to enhance the accuracy of predictions, the model incorporates the influence of geographical factors and architectural structures on the dissemination of pollutants. Of particular significance in evaluating the impacts of brick kilns in urban areas, the model can simulate many sources of pollution simultaneously. However, the AERMOD model has several limitations for evaluating the impacts of brick kilns in Pakistan. Accurate meteorological, land use and emission inventory data are essential prerequisites for the model. The availability and quality of these data often need to be improved in certain regions, thereby diminishing the model's accuracy. The technique also assumes a uniform distribution of pollutants, which may only sometimes be the prevailing condition.

CHAPTER 3

3. METHODOLOGY

The AERMOD dispersion model is used in a multi-stage methodology to assess the impact of brick kilns on the surrounding air quality. The first phase of any research involves acquiring essential data, including emission inventory records, meteorological records, and topographical maps. The provided data has to undergo a process of cleaning and transformation in order to be converted into a format that the AERMOD model can use. The AERMET preprocessor is used to process the meteorological data required by the AERMOD model. Subsequently, the AERMOD model is used to conduct simulations using the input data to evaluate the impacts on atmospheric conditions. Statistical analyses are conducted on the obtained data to validate its precision and dependability. The results are subsequently influenced by other variables, which is the purpose of a sensitivity study. Subsequently, the results are analyzed, and deductions are drawn. Accurate and reliable conclusions need meticulous attention to proper methodology and rigorous validation procedures. The methodology used is crucial in evaluating the impact of brick kilns on the air quality of the surrounding area and identifying potential remedies for the issue of excessive emissions and substandard air quality.

3.1. Technical Details of the Model

The AERMOD (AERMIC Dispersion Model) is an advanced air dispersion model that was collaboratively developed by the Environmental Protection Agency (EPA) and the American Meteorological Society (AMS). Evaluating pollution concentrations emanating from various stationary industrial sources is of utmost importance. This is due to using a Gaussian plume dispersion model specifically designed for short-range applications. The main components of AERMOD consist of the model itself and the AERMET and AERMAP preprocessors.

3.1.1. AERMOD

The AERMOD model functions as the fundamental framework of the system. In this analysis, the calculations for dispersion are conducted. The Gaussian plume dispersion model, known as AERMOD, is used to estimate air pollution dispersion from its source. The dispersion of pollutants inside the plume's cross-section is hypothesized to conform to a Gaussian distribution characterized by a bell-shaped curve, where the center of the distribution aligns with the direction of the wind.

The AERMOD model, like several other models in the discipline, mainly depends on the Gaussian Plume Dispersion Model to forecast the dispersion of air pollutants. A collaborative effort between the American Meteorological Society (AMS) and the Environmental Protection Agency (EPA) of the United States resulted in the development of a mathematical model. This model aims to estimate the dispersion of toxins in the atmosphere by making certain simplifying assumptions. The Gaussian probability distribution is used to postulate that the dispersion of pollutants in the environment conforms to a normal or bell-shaped distribution, thus the designation "Gaussian" for the model. The Gaussian Plume Dispersion Model is predicated on the assumption of a steady-state scenario, whereby the emission of pollutants and meteorological factors remain constant. The actual rate of pollutant emissions and the variability of meteorological conditions might significantly influence the depicted situation, hence necessitating a simplification. The dispersion equations may be simplified, enabling the derivation of analytical solutions that facilitate the estimation of pollutant concentrations over various timeframes and locations.

The basic equation for a Gaussian Plume Dispersion Model is:

$$C(x, y, z) = Q / (2 * \pi * u * \sigma y * \sigma z) * \exp(-y^2 / (2 * \sigma y^2)) * [\exp(-(z-H)^2 / (2 * \sigma z^2)) + \exp(-(z+H)^2 / (2 * \sigma z^2))]$$

where:

$C(x, y, z)$ is the pollutant concentration at a point in space with coordinates (x, y, z).

Q is the pollutant emission rate from the source.

u is the wind speed.

σy and σz are the standard deviations of the concentration distribution in the crosswind (y) and vertical (z) directions, respectively.

These parameters are a measure of the dispersion of the pollutants and depend on the atmospheric stability and the downwind distance x.

H is the effective stack height, which is the physical height of the stack plus the plume rise.

The two exponential terms in the equation represent the Gaussian distributions in the y and z directions, and the two terms in the square brackets account for the reflection of the plume at the ground surface.

The AERMOD model is derived from the Gaussian plume dispersion model, although it has undergone modifications to enhance its versatility and applicability across several environmental contexts. The modeling of the planetary boundary layer (PBL) in AERMOD, the lowest portion of the atmosphere that interacts with the Earth's surface, exhibits significant advancements compared to more basic Gaussian plume models.

The computation of the y and z parameters in AERMOD involves using boundary layer scaling parameters derived via the analysis of meteorological data by the AERMET preprocessor. As a result, AERMOD can consider fluctuations in dispersion properties throughout a spectrum of atmospheric stability conditions and planetary boundary layer (PBL) heights. Estimating dispersion parameters in AERMOD relies on the values derived from AERMET for several factors, such as friction velocity, Monin-Obukhov length, and convective and mechanical mixing heights.

One significant enhancement in AERMOD pertains to its treatment of plume ascent. The concept of "final rise," which disregards the influence of wind speed, air stability, and momentum on the vertical dispersion of pollutants, is often used to simplify basic Gaussian plume models for characterizing plume rise. AERMOD employs a sophisticated approach whereby the plume expansion is dynamically computed as it propagates in the downwind direction. This enhancement enhances the predictive capability of AERMOD in estimating the vertical dispersion of pollutants emitted from elevated sources.

AERMOD also considers the impact of terrain on the dispersion of pollutants. The AERMAP preprocessor determines the elevation of various receptor sites, which AERMOD exploits to refine the dispersion process.

3.1.2. AERMET Preprocessor

AERMET processes the meteorological inputs for the AERMOD air dispersion model. The air dispersion estimation may be conducted using a software application known as AERMET, which was jointly created by the American Meteorological Society (AMS) and the United States Environmental Protection Agency (EPA).

AERMET aims to transform unprocessed meteorological data into a compatible format that AERMOD can interpret. The pollutant dispersion rate estimation occurs after determining boundary layer characteristics and turbulence parameters. AERMET offers processed data about several meteorological parameters, including wind speed, direction, temperature, and atmospheric stability.

The AERMET system can handle data obtained from surface stations, higher altitude data collected by radiosonde observations, and, if available, data gathered from on-site meteorological towers. This enables AERMOD to get a comprehensive and precise understanding of the meteorological variables that influence the dispersion of pollutants.

AERMET involves many distinct phases in the processing of meteorological data. In the first stage, we validate the precision of the unprocessed data obtained from various sources while also addressing any identified deficiencies in the dataset. The data is then transformed into a format that is compatible with AERMOD. In order to proceed with this procedure, it is important to ascertain the values of certain atmospheric parameters, such as the friction velocity, the Monin-Obukhov length, and the convective and mechanical mixing heights.

Multiple mathematical approaches are required to ascertain these values. A metric often used in the field is the roughness length, which is utilized in tandem with the wind speed to ascertain the friction velocity. This parameter quantifies the wind shear in proximity to the surface.

The Monin-Obukhov length serves as a measure of the boundary layer's resilience. Determining some parameters, such as the gravitational acceleration, the buoyancy flux (which exhibits proportionality to the surface heat flux), and the friction velocity, involves substituting specific values into the equations.

Determining the atmospheric boundary layer thickness relies on identifying the altitudes at which convective and mechanical mixing processes occur. These values are obtained using the surface buoyancy flux, sensible heat flux, and friction velocity.

The calculations are based on the theory of atmospheric boundary layer dynamics, which provides the most comprehensive understanding of the atmosphere's behavior in proximity to the Earth's surface. The mathematical approaches used by AERMET are derived from this concept and have undergone rigorous testing using empirical data.

AERMET calculates several turbulence factors to enhance the accuracy of pollutant dispersion rate estimates. Determining the standard deviation of horizontal and vertical wind speeds is contingent upon the friction velocity, the Monin-Obukhov length, and the stability of the atmospheric boundary layer.

3.1.3. AERSURFACE Preprocessor

The AERSURFACE software was developed by the United States Environmental Protection Agency (EPA) as a complementary tool for the AERMOD air dispersion modeling system. Albedo, Bowen ratio, and surface roughness are key surface characteristics in many applications. Albedo refers to the reflectivity of a surface, the Bowen ratio quantifies the efficiency of heat transport, and surface roughness pertains to the irregularity of a surface. These three qualities are often utilized in diverse contexts. Due to their significant impact on the transport and dispersion of pollutants, these parameters have great significance in meteorological and air quality models.

Estimating these three surface characteristics may be achieved using the AERSURFACE interface, which analyses land-use data gathered by the US Geological Survey (USGS). The software processes digital land cover data files and generates pertinent information about a specified geographic area.

The albedo of a surface, which refers to the fraction of incident light or reflected radiation, is influenced by the various kinds of land cover present. Each feature, such as water, evergreen needle-leaf forest, and built-up regions, is given an albedo value. To ascertain the average albedo of a given region, the methodology incorporates the proportional representation of different land uses.

Land use classifications are used to compute the Bowen ratio, which represents the ratio between the sensible heat flow and the latent heat flux of a given surface. Just as albedo is computed, the Bowen ratio is assigned a value for each land use category, which may be used to calculate a weighted average. The Bowen ratio is used to assess the efficiency of heat transmission from the Earth's surface to the atmospheric layer immediately above it. The atmosphere exhibits stability when heat transport is effective, as shown by a high Bowen ratio. Conversely, the atmosphere undergoes instability when heat transfer is inefficient, as indicated by a low Bowen ratio.

The quantification of the unevenness of a landscape may be achieved by measuring its surface roughness. Due to its influence on boundary-layer turbulence, which subsequently affects the dispersion of pollutants, it assumes a vital role in atmospheric dispersion models. The determination of surface roughness in AERSURFACE is based on the logarithm of the ratio between a characteristic height, such as the height of buildings or trees, and a reference height. Similar to the concepts of albedo and the Bowen ratio, the calculation of this parameter is contingent upon the categorization of land use. Nevertheless, the impact of wind direction on surface roughness is notably significant, unlike the other measures, due to the probable presence of anisotropy in land use. Consequently, AERSURFACE may be used to ascertain surface roughness across diverse industrial sectors.

AERSURFACE uses a range of mathematical methodologies, including simple methods, such as weighted averaging, and more intricate approaches, like logarithmic transformations and basic geometry calculations. The use of polygonal representations in land-use classification enables the computation of the proportion of each land-use category within a specified geographical area. Subsequently, weighted averages are used to get albedo and Bowen ratio values, with the weights being assigned based on the proportions of different land uses. Surface roughness assessments often include the use of weighted averages and logarithmic transformations.

It is important to note that the accuracy of AERSURFACE is dependent on many factors, including the size and shape of the user-defined area, the correctness of the given land use data, and the assigned values of albedo, Bowen ratio, and surface roughness for each land use category. It is important to acknowledge the limitations of AERSURFACE when using its findings since it serves as a valuable tool for assessing surface features in air dispersion modeling. However, it is crucial to recognize that AERSURFACE simplifies intricate physical processes.

3.1.4. AERMAP Preprocessor

The AERMOD air dispersion model depends on AERMAP, a terrain preprocessor. The use of AERMAP is necessary for the analysis of digital elevation data and the provision of terrain inputs for AERMOD to achieve precise predictions of pollution dispersion in regions characterized by intricate topography. AERMAP utilizes the unprocessed elevation data to build receptor files, including each receptor's precise coordinates, elevations, and relative gradients.

To accurately include the influence of topography on dispersion estimates, it is essential for AERMOD first to examine the unprocessed digital elevation data. This analysis enables AERMAP to provide terrain-adjusted receptor elevations and hill height scales. In order to accurately account for the influence of intricate topography on the dispersion of pollutants, AERMAP performs preprocessing of terrain data to assist AERMOD.

The processing of digital elevation data obtained from the USGS Digital Elevation Model (DEM) or the Shuttle Radar Topography Mission (SRTM) may be performed using AERMAP. The availability of high-resolution topographic data, such as the datasets mentioned, plays a critical role in accurately predicting the dispersion of contaminants in rugged landscapes.

AERMAP undergoes a series of steps in the compilation of topographical data. Before further procedures, the unprocessed digital elevation data is imported and thoroughly examined for mistakes and inconsistencies. The data is then processed to provide a continuous elevation model for the research area. To ascertain the elevation and hill height scale at every receptor point, it is necessary to interpolate the elevation data into a standardized grid.

The determination of terrain-adjusted receptor elevations and hill height scales necessitates the use of several mathematical approaches. A significant approach involves the computation of the effective hill height scale to assess the quantitative influence of topography on the dispersion of pollutants. An effective hill height scale may be derived by calculating the average heights within a certain distance from each receptor. The weights are determined by considering the topographic gradient and the spatial separation between the receptor and each elevation point.

Determining the terrain adjustment parameters is an essential technique used in AERMAP. The factors under consideration impact the standard deviations of pollutant concentrations in the crosswind (y) and vertical (z) directions due to the influence of topography on dispersion characteristics. AERMAP uses the effective hill height scale and the slope of the terrain at each receptor site to ascertain the requisite terrain adjustment factors.

AERMAP is used to ascertain the disparity in elevation between the receiver and the source to calculate the terrain adjustment parameters. The terrain adjustment factor may be estimated by using the effective hill height scale and considering the slope of the terrain, particularly when the receptor is situated at a greater elevation than the source. The terrain adjustment factor is determined by considering the distance between the source and the receptor, as well as the slope of the terrain. This factor is particularly relevant when the receptor is situated at a lower height than the source.

The dispersion calculations in AERMOD include the terrain features via the use of terrain adjustment factors. Enhanced accuracy in predicting pollutant concentrations may be achieved in regions characterized by intricate topography using modified dispersion calculations. These calculations include the influence of terrain on pollutant dispersion.

3.1.5. Integration of AERMOD, AERMET, and AERMAP

Integrating AERMOD, AERMET, and AERMAP enhances air pollution dispersion assessment's dependability, precision, and efficiency. AERMOD enables dispersion estimation using meteorological data from AERMET and topographical information from AERMAP. When assembled, these components provide a comprehensive system capable of accurately simulating the dispersion of pollutants over various scenarios. AERMET and AERMAP are two software tools that provide the dispersion model with essential meteorological and topographical information via their separate outputs. AERMET is a software tool that transforms some components of the unprocessed meteorological data, crucial for understanding the dispersion of pollutants inside the Planetary Boundary Layer (PBL), into a format that AERMOD can effectively use. However, AERMAP functions inversely by analyzing the topography to elucidate the influence of the terrain on the propagation and dispersion of atmospheric pollutants.

AERMOD utilizes the provided inputs and emissions data to model the atmosphere's dispersion of pollutants. The Gaussian plume dispersion theory, with appropriate modifications to account for the intricacies inherent in real-world scenarios, enables the estimation of pollutant concentrations over several temporal and spatial domains. The modular nature of the AERMOD system enables simple customization to cater to a diverse array of applications. AERMOD can provide precise predictions regardless of the source's elevation, whether at ground level or at a higher altitude. Additionally, AERMOD can accurately forecast outcomes in simple and complex topographical settings. Furthermore, AERMOD effectively provides accurate forecasts regardless of the prevailing weather conditions, whether calm or turbulent.

3.2. Key Features of Lakes Environmental AERMOD View

AERMOD, a state-of-the-art air dispersion model developed by the American Meteorological Society (AMS) and the U.S. Environmental Protection Agency (EPA), incorporates several key features that significantly enhance its capabilities over previous models. These features include the treatment of the atmospheric boundary layer, the calculation of plume rise, the incorporation of terrain effects, and a modular design.

The atmospheric boundary layer (ABL) is the lowest part of the atmosphere, where interactions with the earth's surface occur. AERMOD incorporates a planetary boundary layer (PBL) model that includes treatment of both surface and elevated sources and provides a more realistic representation of the dispersion and transport processes occurring within the ABL. Unlike previous models that used constant dispersion coefficients, AERMOD's PBL model includes a dynamic calculation of dispersion coefficients based on meteorological conditions.

The meteorological preprocessor, AERMET, supplies AERMOD with meteorological data that includes boundary layer parameters like the friction velocity, the Monin-Obukhov length, and the convective and mechanical mixing heights. These parameters are used by AERMOD to calculate the dispersion parameters in the Gaussian plume model. The friction velocity is a measure of the wind shear near the surface, while the Monin-Obukhov length characterizes the atmospheric stability. The convective and mechanical mixing heights represent the depth of the boundary layer under convective and mechanically driven conditions, respectively. AERMOD uses these parameters to calculate the dispersion of pollutants dynamically, based on the state of the atmosphere.

Another key feature of AERMOD is its treatment of plume rise. The plume rise is the additional height that a plume of pollutants reaches due to the buoyancy of the hot gases emitted from a source. This can significantly influence the dispersion of pollutants, especially for elevated sources such as smokestacks. AERMOD calculates the plume rise dynamically as the plume travels downwind, considering the effects of wind speed, atmospheric stability, and momentum. This allows AERMOD to predict the vertical dispersion of pollutants more accurately, especially for elevated sources.

AERMOD also incorporates the effects of terrain on pollutant dispersion. The terrain preprocessor, AERMAP, processes digital elevation data to create input for AERMOD that includes the terrain height at various receptor locations. Terrain can significantly influence the dispersion of pollutants, especially in areas of complex terrain. AERMOD's ability to account for these effects is a significant improvement over previous models, which either ignored terrain effects or treated them simplistically.

The modularity of AERMOD is another key feature. The AERMOD system includes separate components for processing meteorological data (AERMET), terrain data (AERMAP), and performing the dispersion calculations (AERMOD). This modular design allows for improvements to be made to each component independently, and also allows users to replace or modify specific components to suit their specific needs.

AERMOD also includes algorithms for handling other complex dispersion scenarios. For example, it includes algorithms for building downwash, which is the deflection of the plume towards the ground due to the presence of buildings or other obstacles near the source. It also includes algorithms for handling coastal interfaces, where the transition between land and water can affect the dispersion of pollutants.

Moreover, AERMOD provides options for modeling both short-term and long-term pollutant concentrations. For short-term modeling, AERMOD uses hourly meteorological data to calculate hourly average pollutant concentrations. For long-term modeling, AERMOD can use multiple years of meteorological data to calculate annual average concentrations or to calculate the highest concentrations expected over a specific averaging period, such as 24-hours or 1-hour.

AERMOD's capabilities are not limited to a single pollutant or a single source. The model allows for the modeling of multiple pollutants and multiple sources simultaneously, providing a comprehensive picture of the air quality in a region. This feature is critical for realistic modeling of real-world scenarios, where multiple sources often coexist, and where the effects of different pollutants need to be assessed together.

AERMOD is also designed to handle both continuous and intermittent emissions. It can account for variations in the emission rate over time, which is important for sources such as industrial facilities, which may have fluctuating emission rates due to variations in production levels.

Another feature is AERMOD's ability to incorporate deposition and chemical transformation processes. The model can account for the removal of pollutants from the atmosphere due to dry deposition and wet deposition, and it can also account for the transformation of pollutants due to chemical reactions. This is particularly important for pollutants such as sulfur dioxide and nitrogen oxides, which can undergo chemical reactions in the atmosphere to form secondary pollutants like sulfate and nitrate particles.

AERMOD also offers flexibility in the selection of receptor locations. A receptor in air dispersion modeling is a specific location where the model calculates the pollutant concentration. AERMOD allows for the specification of receptor locations in a grid pattern, in a discrete list of coordinates, or in a combination of both. This provides flexibility in assessing the impact of pollutant dispersion, whether the interest is in the overall spatial distribution of pollutants or the pollutant concentrations at specific sensitive locations, such as residential areas, schools, or hospitals.

The model also supports multiple output options. The results of an AERMOD run can be output in a format suitable for further analysis with other software, such as GIS software for spatial analysis. This allows users to visualize the dispersion of pollutants in a graphical format, which can be helpful for understanding the impact of a source on air quality.

3.3. Requirements to Run AERMOD

AERMOD Dispersion Model requires meteorological, land cover, and terrain data primarily to run efficiently.

3.3.1. Requirements for AERMET

The AERMOD air quality dispersion model uses AERMET as its meteorological data preprocessing tool. Obtaining the necessary input data is a fundamental aspect of facilitating the functioning of AERMOD. The following section provides a more comprehensive discussion of the requirements for executing AERMET.

The first stage involves addressing the necessary hardware and software components. In order to ensure optimal performance, AERMET must be executed on a computer system of superior quality. Given the extensive scale of meteorological information AERMET processes, using a robust computer system equipped with enough memory capacity is very advantageous. AERMET's data files, including both input files used by the software and output files generated by it, might be of considerable size. As a result, it is crucial to have enough storage capacity available. The AERMET application may be executed using a command-line interface, while graphical user interfaces (GUIs) are also commercially accessible for acquisition. Although not essential, graphical user interfaces (GUIs) may enhance the ease of installation and operation of AERMET, especially for those unfamiliar with command-line interfaces.

AERMET mainly depends on meteorological data. AERMOD's input parameters are generated by processing meteorological data obtained from ground-based and sky-based sources. Including meteorological parameters such as wind speed and direction, air temperature, and cloud cover is crucial in surface data collection. The National Climatic Data Centre (NCDC) and other meteorological databases are reliable sources for accessing this information. In order to adequately include seasonal variations in meteorological conditions, it is important to ensure that the dataset encompasses a whole year cycle.

Comparatively, upper air data provide information on the atmospheric conditions above the tropopause. Data examples often include parameters such as temperature, pressure, wind speed, and wind direction at different heights. Generally, these values are obtained using radiosonde observations, which include launching weather balloons equipped with meteorological instruments to collect atmospheric readings while the balloon ascends. The National Weather Service and other meteorological data providers often grant public access to radiosonde data.

AERMET necessitates the inclusion of the surface data-gathering site. This dataset includes the site's anemometer height, latitude, and longitude and the elevation at which wind speed and direction measurements were recorded. Another essential parameter is the roughness length, which quantifies the degree of roughness shown by the surrounding terrain near the specified site. If such data is unavailable, an estimate may be derived by using land use and land cover data.

AERMET may be used in combination with localized meteorological information. If this information is readily available, it might potentially provide a more accurate representation of the regional climate conditions. It is necessary to monitor several parameters, such as wind speed, direction, and air temperature, at different heights within the designated location. It is important to exercise caution and verify the authenticity and trustworthiness of this material prior to its use.

In summary, AERMET necessitates the establishment of many control parameters. This study provides information on the temporal parameters, including the commencement and termination timings, as well as the time zone and units of measurement used for the meteorological data. Additional options that may be chosen include

- the criteria used to determine the stability or instability of the environment,
- the method used to estimate missing data and
- the mechanism utilized to alter the wind direction..

3.3.2. Requirements for AERMAP

AERMAP is the terrain preprocessor for the AERMOD air quality dispersion model. It plays a crucial role in incorporating terrain effects into the dispersion calculations performed by AERMOD. To run AERMAP successfully, several requirements must be met, which are discussed below in detail.

The primary input requirement for AERMAP is terrain data. AERMAP processes digital elevation models (DEMs) to derive terrain parameters necessary for AERMOD's dispersion calculations. DEMs are datasets that represent the elevation of the earth's surface at regularly spaced intervals. These datasets are typically obtained from sources such as the U.S. Geological Survey (USGS) or other similar organizations. It is important to ensure that the DEM used is compatible with AERMAP's requirements in terms of file format and accuracy.

The accuracy and resolution of the DEM are crucial factors that can influence the quality of the terrain representation in AERMOD. Higher resolution DEMs capture more detailed terrain features, allowing for more accurate dispersion calculations, particularly in areas with complex topography. It is recommended to use DEMs with a resolution of at least 10 meters or finer for accurate terrain representation.

In addition to the DEM, AERMAP also requires information about the location and characteristics of the receptors. Receptors are specific locations where AERMOD calculates pollutant concentrations. The latitude, longitude, and elevation of these receptor locations must be specified. Receptors can be defined as individual points or as a grid covering the area of interest. The receptor locations should be chosen strategically to capture areas of interest, such as sensitive receptors like residential areas, schools, or hospitals.

AERMAP also allows for the specification of receptor elevations adjusted for the terrain height. This feature enables the modeling of pollutant concentrations at specific heights above the terrain, which can be useful for assessing impacts at different levels within the atmospheric boundary layer.

The process of running AERMAP involves several control options that can be specified to tailor the output to specific requirements. These options include the specification of the distance from each receptor at which terrain adjustments are performed. This distance determines the extent to which the terrain height affects the dispersion calculations. Additionally, AERMAP offers the ability to specify a minimum search distance for nearby terrain features, which allows for more accurate calculations in areas with complex terrain.

AERMAP also provides options for the treatment of water features, such as lakes and rivers. These options enable the consideration of specific dispersion characteristics associated with such features. Water bodies can significantly affect pollutant dispersion, and AERMAP allows for their representation in the dispersion calculations.

It is important to note that the accuracy of the terrain data used by AERMAP can have a significant impact on the accuracy of the dispersion calculations. Therefore, it is recommended to ensure the quality and accuracy of the DEMs used. Careful validation and verification of the terrain data against ground truth measurements, where available, can help ensure reliable results.

3.3.3. Control Data

Control data plays a critical role in the proper functioning of the AERMOD air quality dispersion model. These specifications and settings determine how the model operates and how the dispersion calculations are performed. Accurately defining the control data is essential to obtain reliable and meaningful results from AERMOD. Let's explore the key requirements in detail.

3.3.3.1.Averaging Period

The averaging period refers to the time interval over which the pollutant concentrations are calculated. AERMOD allows for the specification of different averaging periods, such as hourly, daily, or annual averages. The selection of the appropriate averaging period depends on the objectives of the analysis and the relevant regulatory requirements or guidelines.

3.3.3.2.Simulation Period

The simulation period defines the duration for which the dispersion calculations are performed. It is crucial to specify the start and end times of the simulation to capture the relevant time frame of interest. The simulation period should align with the temporal variability of the emissions and meteorological conditions being considered.

3.3.3.3.Time Zone

AERMOD requires the specification of the time zone for the meteorological data and simulation period. This ensures that the model accurately accounts for the local time and adjusts the meteorological data accordingly. Different time zones can have variations in solar radiation, atmospheric stability, and other meteorological parameters, which can impact the dispersion calculations.

3.3.3.4.Units of Measurement

It is vital to specify the units of measurement consistently for various parameters used in AERMOD. This includes emission rates, wind speed, distances, and other relevant quantities. Ensuring uniformity between the units used for emission rates and the other parameters helps avoid errors in the dispersion calculations and ensures accurate results.

3.3.3.5.Missing Data Handling

In cases where there are gaps or missing data in the meteorological dataset, AERMOD provides options for handling these missing data. Various methods, such as statistical interpolation or data estimation based on nearby stations, can be employed. The selected method should reflect the best estimation of the missing data, considering factors like data quality and the availability of nearby meteorological observations.

3.3.3.6.Wind Direction Adjustment

AERMOD allows for the adjustment of wind direction data to account for potential biases or inaccuracies in the measured wind direction. This adjustment ensures that the wind direction used in the dispersion calculations is representative of the actual meteorological conditions. Several methods, such as linear interpolation or wind sector adjustment, can be utilized to correct the wind direction data.

3.3.3.7.Atmospheric Stability Criteria

AERMOD employs different criteria to categorize atmospheric stability conditions. The selection of the appropriate stability criteria is crucial as it determines how AERMOD treats atmospheric stability and influences the dispersion calculations. AERMOD provides options to choose stability criteria based on parameters like the Monin-Obukhov length, the Richardson number, or other stability indices.

3.3.3.8.Grid Resolution

In AERMOD, receptors can be defined as individual points or as a grid covering the area of interest. If a grid is used, the resolution of the grid must be specified. The grid resolution determines the spacing between receptors and impacts the level of detail in the dispersion calculations. A finer grid resolution captures more localized variations in pollutant concentrations but requires more computational resources.

3.3.3.9.Output Options

AERMOD offers flexibility in terms of the output options. Users can specify the desired format and content of the output files generated by the model. This includes options to select specific output variables, the format of the concentration output files (e.g., ASCII or binary), and choices for writing summary statistics or concentration grids.

Careful consideration and accurate specification of the control data are crucial for running AERMOD effectively. Improper specification of control data can lead to erroneous dispersion calculations and misinterpretation of the air quality impacts. It is essential to review the requirements and guidelines provided.

3.3.4. Source and Emission Data

The Atmospheric Dispersion Modeling System (AERMOD) is a highly advanced atmospheric dispersion model used by environmental professionals to assess the impact of emissions from industrial sources on air quality. The inputs required for AERMOD can be categorized into two major sections: meteorological data and source emissions data. The focus here will be on the requirements of source and emission data for AERMOD.

Source data refers to detailed information about the emission sources from which pollutants are released into the atmosphere. For AERMOD, this data is critical as it provides the model with information on the characteristics and the location of the emission sources. It includes details about stack height, stack diameter, stack gas exit velocity, stack gas temperature, and the geographical coordinates of the source.

The stack parameters are vital because they influence the initial dispersion characteristics of the pollutants. For instance, the stack height can influence the initial vertical distribution of the pollutants, with higher stacks typically leading to pollutants being released higher in the atmosphere. Similarly, stack diameter, exit velocity, and gas temperature can impact the initial dilution of the pollutants. The geographical coordinates provide the exact location of the emission source, which aids in determining the impact on various receptor locations.

Emission data is the information about the pollutants being emitted from the sources. This includes details about the type of pollutants, emission rates, and the operational schedule of the sources.

The type of pollutants is critical because different pollutants can have different impacts on the environment and human health, and they may disperse differently in the atmosphere. For instance, gases may disperse differently compared to particulate matter. Some pollutants may also undergo chemical transformations in the atmosphere, further affecting their dispersion.

The emission rates provide information about the quantity of pollutants being emitted over a specific time. This is often provided in units such as grams per second (g/s). Emission rates are crucial as they directly impact the concentration of pollutants in the atmosphere.

The operational schedule of the sources is important because emissions may not occur continuously. Some sources may operate only during certain hours of the day or certain days of the week. Information on the operational schedule helps the model accurately predict pollutant concentrations based on when the emissions are occurring.

Another crucial aspect of emission data is the emission release parameters, which include the pollutant release height, the initial vertical and horizontal spread of the emission plume, and the initial vertical and horizontal velocity of the pollutants. These parameters are critical for the model to accurately predict the initial dispersion of the pollutants immediately after they are released from the source.

Collecting accurate source and emission data is a crucial step in the AERMOD modeling process. It requires a thorough understanding of the emission sources and the pollutants being emitted. Often, this information can be obtained from the facility's operational records, stack tests, or emission inventories. In some cases, the data may need to be estimated using engineering calculations or emission factors.

Once the source and emission data is collected, it needs to be input into the AERMOD model in a format that the model can understand. This typically involves preparing a detailed input file that contains all the required data. The input file must follow a specific format as defined by the AERMOD user guide, with each piece of data entered in the correct location and in the correct units.

3.3.5. Receptor Data

The AERMOD air quality dispersion model relies heavily on receptor data since it specifies the precise sites at which pollutant concentrations are estimated. To get useful and trustworthy findings using AERMOD, accurate and representative receptor data is required. There are a few stipulations that need to be completed before one may submit receptor data to AERMOD.

First, we must pinpoint the precise areas from which we will draw our pollution estimates. Individual points or a grid encompassing the target region might be called receptors. Sensitive receptors, such as residential areas, schools, hospitals, or other ecologically relevant places, should be included in a strategic selection of receptor placements. Objectives and probable repercussions of pollution dispersion should inform receptor site selection.

Locating each receptor requires accurate geographic coordinates. The latitude and longitude values provide positional information regarding north-south and east-west orientation. Without these coordinates, the receptors cannot be placed on the map or compared to AERMOD's dispersion estimates. To ensure your geographical coordinates are spot-on, utilize a GPS or a top-notch mapping program.

One of AERMOD's most fundamental preconditions is a rise in receptor expression. It is the elevation above MSL when estimates of pollutant concentrations will be made. Digital elevation models (DEMs) and topographic maps are sources for this information. The correct description of atmospheric conditions and the computation of plume rise at the receptor site rely on an accurate assessment of the receptor height. In order to make precise dispersion estimates, it is essential to collect elevation data that is representative of the real terrain height at the receptor sites.

The receptor's elevation above ground level should also be considered. Allowing users to define receptor heights allows AERMOD to account for a wide range of ABL concentrations. Different analyses may call for different receptor heights, such as when estimating concentrations at ground, rooftop, or any other height of interest. The receptor height matters because it affects the ABL's representation of dispersion and enables the recording of concentrations at discrete sites.

The receptor data's geographical distribution should also be considered. A proper geographical distribution of receptors is necessary to reflect the region of interest accurately. It is important to consider the features of the research region and the goals of the analysis while deciding on the density and pattern of receptor sites. A thorough evaluation of pollutant concentrations is made possible by the high spatial resolution provided by dense receptor grids. On the other hand, sparse grids come in handy when more attention must be paid to widespread effects.

To provide more dispersion analysis more background, it is possible to apply other features or qualities to each receptor. Attributes like land use, building height, proximity to sensitive receptors, and other contextual information may be used to understand the findings better and draw conclusions from the analysis. Incorporating such characteristics may improve comprehension of the possible effects of pollution dispersion and facilitate decision-making. Maintaining accurate and comprehensive receptor data is essential. You may double-check the precision of the given coordinates using a GPS or other accurate mapping tools. Validating elevation data using ground-truth measurements or other accurate references is essential. It is important to precisely measure or estimate receptor heights about the sites of interest. The geographical distribution of emission sources and possible pollution transport paths should be considered while choosing receptor sites. When assessing the possible effects on human health, ecosystems, or the environment, sensitive receptors, such as residential or ecologically important places, should be prioritized.

Finally, keeping the receptor data up-to-date and in good shape is crucial. It may be necessary to reevaluate and revise the receptor sites to appropriately represent the current environment considering changes in land use, urban growth, or the introduction of new emission sources. The accuracy of dispersion predictions depends on regularly updating receptor data to account for changing environmental circumstances.

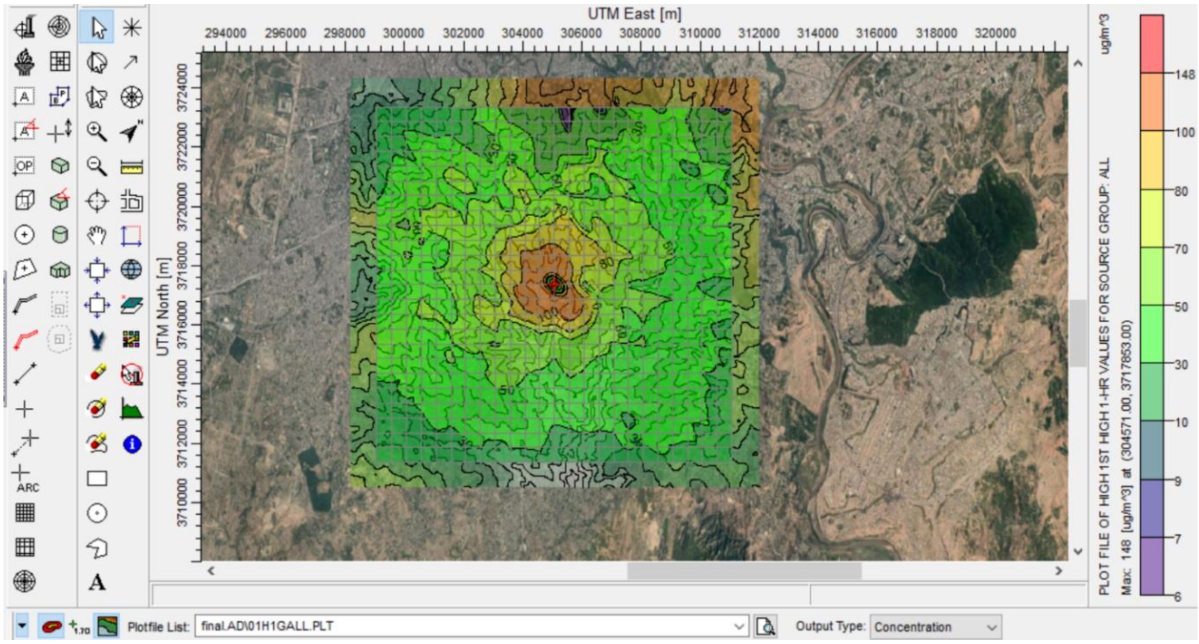
3.3.6. Terrain Data

The AERMOD dispersion model relies heavily on correct terrain data to provide reliable air quality predictions. Because of its ability to consider the impacts of topography on pollutant dispersion, AERMOD requires accurate and up-to-date terrain data. If the necessary terrain data is available, AERMOD will be able to consider the effect of topography on the dispersion and migration of pollutants. The following are important factors and prerequisites for AERMOD terrain data.

To begin, trustworthy sources should be used to collect terrain data. Digital elevation models (DEMs), which offer information on the height of the earth's surface, are the most prevalent source of topography data. The United States Geological Survey (USGS) and other comparable organizations are common places to seek DEMs. The DEMs utilized for AERMOD must be up to par regarding precision, resolution, and model compatibility.

The precision of terrain information is crucial. Elevational data from the DEMs should be precise enough to be useful. Errors in the dispersion calculations, caused by inaccurate or out-of-date elevation data, might lead to erroneous findings. DEMs' veracity may be checked by contrasting them with measurements taken on the ground or other trusted resources.

Resolution describes how finely granular the terrain data is. High-resolution DEMs are more reliable since they capture more minute details of the landscape. For more accurate modelling of the impacts of the topography on pollutant dispersion, AERMOD works better with higher-resolution terrain data, particularly in locations with complicated terrain. DEMs should have a resolution of 10 metres or more for reliable terrain depiction.



PLOT FILE OF HIGH 1ST HIGH 1-HR VALUES FOR SOURCE GROUP: ALL

Max: 148 [ug/m^3] at (304571.00, 3717853.00)

Plotfile List: final.AD\01H1GALL.PLT

Output Type: Concentration

Figure 3-1An example of terrain output generated from AERMAP preprocessor

The source and receptor locations and the surrounding region must be included in the terrain data. Coverage should go beyond the local neighborhood of the sources to properly account for the various routes and dispersion patterns of pollutants. This guarantees that AERMOD may properly account for the impact of topographical elements throughout the modelling domain.

The geographical scope of the terrain data should also be suitable for the research area. A sufficient buffer zone should be included to mitigate the effects of the surrounding region. Because the effects of topography extend beyond the surrounding region, this is especially crucial when modelling near the research domain's boundaries. The terrain data must be supplied in a format that AERMOD understands. The "Arc/INFO ASCII Grid" format, or a format that can convert to it, is ideal for storing terrain data for use with AERMOD. If you want your terrain data to work with AERMOD, you must ensure it is in the right format.

Moreover, AERMOD provides choices for handling the presence of water in the form of lakes, rivers, or coasts. With these choices, you may think about the unique dispersion properties of certain elements. Assuring that AERMOD's representation of dispersion patterns at land-water interfaces is correct requires including water features in the terrain data.

It may be required to update the terrain data regularly to account for changes in the landscape due to shifting land uses, urbanization, and natural occurrences. Pollutant dispersal may be affected by topographical changes, particularly in dynamic situations. The reliability of AERMOD relies on the accuracy of the terrain data being kept up to date.

3.4. Outcome Features

The AERMOD air dispersion model produces several outcome features that provide valuable insights into the dispersion and concentration of pollutants in the atmosphere. These outcome features help assess the potential impact of emissions on air quality and support decision-making processes.

3.4.1. Concentration Contours

The AERMOD air dispersion model provides useful results, including concentration contours. They are helpful visual depictions of how air pollution moves through the atmosphere, revealing the pattern of pollution's spread throughout a given area. Concentration contours, also known as concentration contour areas, are lines or regions that connect sites of uniform pollutant concentration to produce a contour map.

AERMOD's concentration contours reveal where pollution is concentrated and where it is comparatively low. Dispersion patterns over the modelled area may be seen graphically in the contours shown on a map or grid. Depending on the weather, the location of emission sources, and the topography, the contours may take on various forms and densities.

Users may check for areas of concern, including hotspots or areas with increased pollution levels, by looking at the concentration contours. Pollutant hotspots are localized regions where ambient levels of air pollution are much greater than in neighboring places. To safeguard human health or sensitive receptors, investigating or mitigating these hotspots may be necessary.

Users may evaluate pollution dispersion's geographical breadth and gradients using the concentration contours. Steep concentration gradients, shown by contour lines that are close together, indicate fast variations in pollution levels and draw attention to specific regions where effects are concentrated. Widely separated contours, on the other hand, show that pollution levels are declining gradually as they spread and dilute across greater regions.

Dispersion paths and possible problem regions outside the immediate proximity of emission sources may be identified using contour maps, which give a thorough perspective of the dispersion patterns. This spatial awareness is helpful for land-use planning, source siting, and control tactics by identifying receptor sites that pollution emissions may most impact.

Users of AERMOD may adjust the concentration values at which the contours are created, allowing for a high degree of personalization. Users may choose suitable contour intervals based on applicable regulations, health rules, or the needs of a certain project. Users may zero in on particular regions of interest or check for compliance with predetermined concentration limits by altering the contour levels.

Concentration contours show how a pollutant spreads in a given area under atmospheric and emission parameters. Variations in wind speed, wind direction, and atmospheric stability may strongly impact concentration contours and dispersion patterns. Concentration contour interpretation must thus consider the temporal variability and representativeness of the meteorological data.

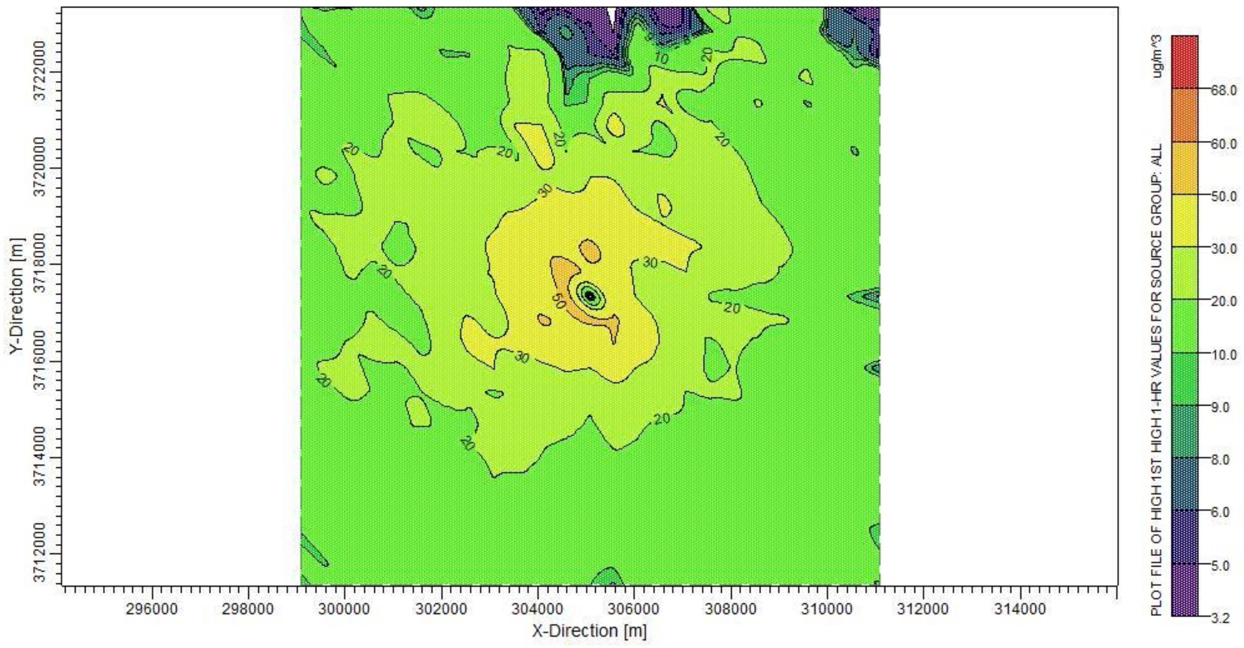


Figure 3-2An example of generated concentration map of PM2.5 obtained from AERMOD

Concentration contours may be examined more deeply than only visually, yielding useful insights. Users may determine the extent of regions impacted by a given pollutant concentration by calculating the area or volume contained by certain contour levels. You may use this data to estimate the population of receptors within a certain concentration threshold or to determine the extent and magnitude of regions of possible influence.

Potential consequences may be evaluated more thoroughly by overlaying concentration contours with sensitive receptors, land-use data, or other spatial information. Users may determine which sensitive receptors, such as homes, schools, or hospitals, are more likely to be exposed to dangerously high amounts of pollution by comparing the contour maps to the locations of these receptors. Land use planning, source siting, and introducing control mechanisms may all benefit from this data.

In addition, scenario analysis and model assessment may benefit from using concentration contours. Users may evaluate the efficiency of control mechanisms by comparing the concentration contours generated by various emission scenarios or mitigation schemes. This facilitates the assessment of the consequences of alternative approaches to lowering emissions, as well as the effects of varying emission rates and source configurations.

One may overlay concentration contours on topographic maps, aerial images, or other geospatial data in AERMOD for better visualization and understanding, among other features. Users may build contour maps with color-coded or shaded contours to better grasp the distribution patterns. The interpretation of concentration contours requires consideration of the individual modelling aims and the intended application of the findings. However, these visualization techniques help communicate modelling results and ease interactions with stakeholders or regulatory authorities. Pollutant dispersion and possible repercussions in the modelled region may be better understood using concentration contours. However, they should be utilized along with other characteristics and data on the outcomes to get a full picture of the state of the air quality.

The restrictions and uncertainties of concentration contours must be considered. To function, the AERMOD model requires inputs such as weather, emissions, and topographic information. The precision of the concentration contours may be affected by uncertainties in the input parameters, which can then propagate into the dispersion estimates. If users want accurate outputs, they should assess the input data for its representativeness and quality with great care.

Furthermore, concentration contours only show the distribution of pollutants in each environment at a given time; they do not account for the fluctuations in pollution levels over time. Weather, day/night cycles and seasonal effects may all cause shifts in dispersion patterns and concentration contours over time. To get a fuller picture of the air quality conditions, users should consider the temporal variability and conduct assessments spanning many periods.

3.4.2. Wind Rose Plots

The AERMOD air dispersion model's wind rise plots are a useful result feature since they show the spectrum of wind directions and velocities. Users may get insight into typical wind patterns and how they affect pollution dispersion using wind roses. Users may evaluate the effects of wind conditions on air quality by analyzing wind rise plots, which provide insights into the possible paths of pollutants.

A wind rose plot is a circular figure with sectors indicating different wind directions. Within each section, the length of the radial lines indicates the percentage of time wind coming from that direction. The radial lines are often colored or color-coded to show the variation in wind speed throughout each sector.

Users may see how often and strongly winds blow from various directions with the wind rose plot that AERMOD creates. Knowing the predominant wind directions and how fast they blow at the modelling location is only possible with this data. To better understand how wind patterns affect pollution dispersal, a wind rise plot may be used to visualize the most common wind conditions quickly and easily.

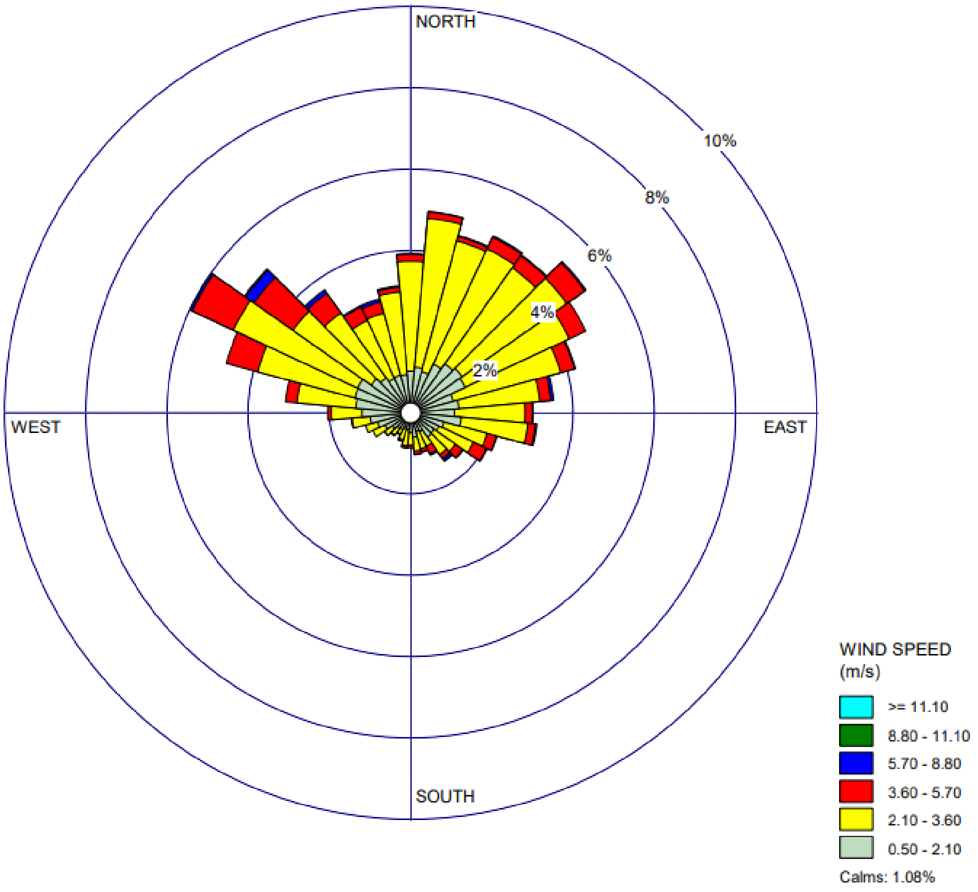


Figure 3-3An example of generated WIND ROSE plot through AERMET preprocessor

Insights on the possible transport paths of pollutants released from sources may be gained by analysis of wind rose plots. By considering the prevailing wind directions, users may anticipate the path pollutants will take from emission sources to receptor sites. This data is helpful for pinpointing impact zones and gauging how vulnerable receptors are to pollution in various wind conditions.

Additional information regarding the dispersion characteristics may be gleaned from the wind rose plot, which depicts the distribution of wind speeds. Higher wind speeds are represented by longer radial lines emanating from the plot's centre, while shorter lines show lower wind speeds. Using this data, users may evaluate the likelihood of pollution diluting and spreading under various wind conditions.

In order to pinpoint areas that are more likely to be affected by elevated pollution levels, the wind rose plot combines data on wind direction and wind speed. Pollutants are more likely to be transferred and impact surrounding receptors in sectors with longer radial lines and greater wind speeds. Users may then prioritize monitoring and mitigation activities in the most pressing identified sectors.

The influence of topographical factors on the dispersion of pollutants may be evaluated using wind rose plots. Hills, mountains, and valleys may all affect how the wind behaves and how much pollution is dispersed in their immediate neighborhood. To analyze pollutant dispersion more accurately in complicated terrain, users may acquire insights into how terrain characteristics impact wind direction and speed by analyzing wind roses in combination with terrain data.

Wind rise plots may be compared with receptor locations and emission sources to investigate further the possible impact of wind direction on pollutant concentrations at receptors. Important receptor areas at greater risk of exposure to contaminants under certain wind conditions are identified using this study. To protect vulnerable receptors and guarantee adherence to air quality requirements, it enables focused monitoring or mitigation efforts.

AERMOD allows users to customize the time range and granularity of the wind direction bins used to generate wind rise plots. Users may choose the most suitable time interval for their analyses, such as hourly or monthly data. You may also change the number of bins used to categorize the wind's direction to get the precision you want in the wind rose plot.

The reliability of the meteorological data used to create wind rose plots should be carefully considered. For the wind rise analysis to be trustworthy, meteorological data, such as wind speed and direction observations, must be accurate and high-quality. To guarantee accurate and representative findings, users should double-check the meteorological data's sources, quality control methods, and period covered.

3.4.3. Plume Rise

In the AERMOD framework, plume rise is crucial in making reliable predictions of pollution dispersion in the air. The vertical distance a pollution plume travels from its source due to buoyancy forces is known as the plume rise. It is critical to remember that the plume rise does not refer to the height of the plume's peak but rather to the vertical distance between the emission point and the plume's centerline. Predicting the height of a plume is crucial for calculating the amounts of pollutants at ground level, which in turn affects public health risk and environmental impact evaluations.

AERMOD's plume rise feature uses Briggs' methods for estimating plume rise, which account for both momentum and buoyancy-induced plume rise. The data used to develop these algorithms may be classified into two broad classes: continuous and puff plumes. Continuous plumes, such as those emitted by smokestacks, rise because of their starting velocity and the buoyancy caused by the temperature differential between the plume and the surrounding air. To ascend, puff plumes like those produced by explosions or batch releases rely mostly on their initial velocity and dissipate quickly.

Several parameters, including plume temperature, ambient air temperature, plume velocity at the stack exit, and stack diameter, are considered by the AERMOD model to calculate the plume rise. Buoyant plums gain upward momentum from the stack gas exit velocity and the temperature differential between the plume and the surrounding air. When the plume's temperature is the same as the surrounding air, the buoyancy forces stop acting, and the plume falls back to the ground. Even though the plume's temperature is the same as the surrounding air, its initial velocity might cause it to ascend higher.

The downwash results from tall buildings are accounted for in AERMOD's rising plume feature. Increased concentrations of ground-level pollutants come from downwash, which happens when a plume is trapped in the turbulent wake of a building or structure and driven downward. Downwash effects are estimated more precisely because PRIME (Plume Rise Model Enhancements) project algorithms are included in the model.

The capacity of AERMOD to consider the impacts of variable atmospheric stability on plume rise is another significant component of this functionality. The vertical motion of the atmosphere, measured by the term "atmospheric stability," may have a major impact on pollution dispersal. In order to categorise the air stability and adapt to the plume rise appropriately, AERMOD employs the Monin-Obukhov length and other meteorological data.

Finally, it is important to note that AERMOD takes geography into account when calculating the height of a plume. The concentration of pollutants near the ground may be altered if a plume reaches a hill or mountain and is pushed higher or downwards by the topography. AERMOD improves forecast accuracy in places with complicated topography by factoring in the influence of the terrain itself during the plume rise computation.

CHAPTER 4

4. RESULTS AND DISCUSSOIN

4.1. RESULTS

Significant findings about the application of the AERMOD dispersion model to brick kilns in the Islamabad, Pakistan setting were presented by the research. To better comprehend how brick kiln emissions, a key source of local air pollution, are dispersed, this modelling method was used.

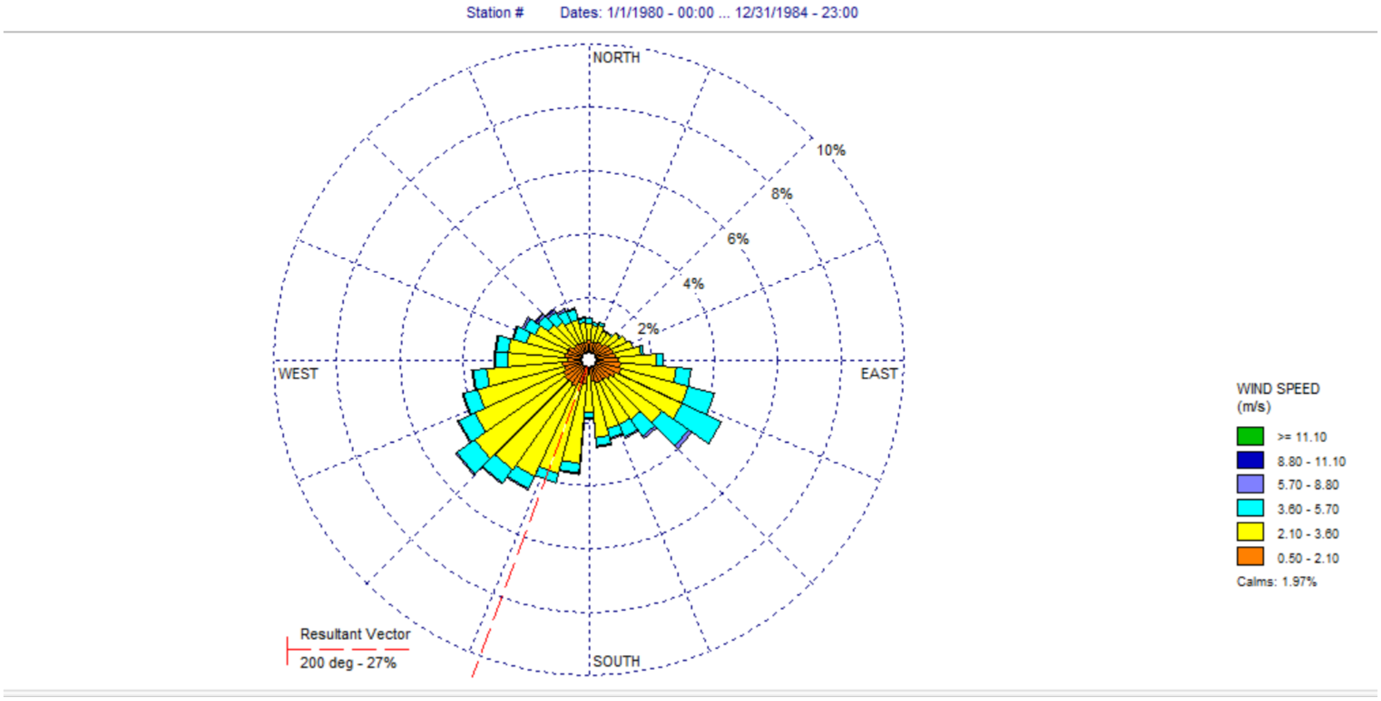


Figure 4-1WIND ROSE PLOT of the Study Area

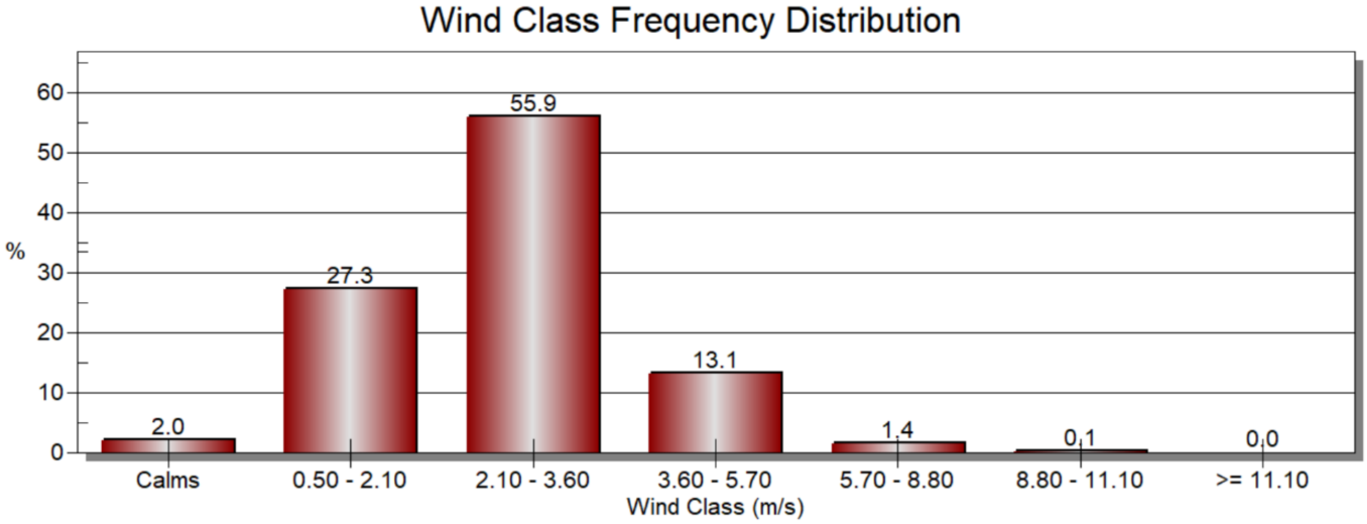


Figure 4-2Graph representing Wind class frequency distribution

In the analysis, the AERMOD model was set up utilizing three years of meteorological data from Islamabad, emissions data from the brick kilns, and geospatial information about the topography and land use. The brick kiln emissions were found to significantly contribute to the total suspended particulates (TSP), PM_{10}, and PM2.5 concentrations in the atmosphere of Islamabad.

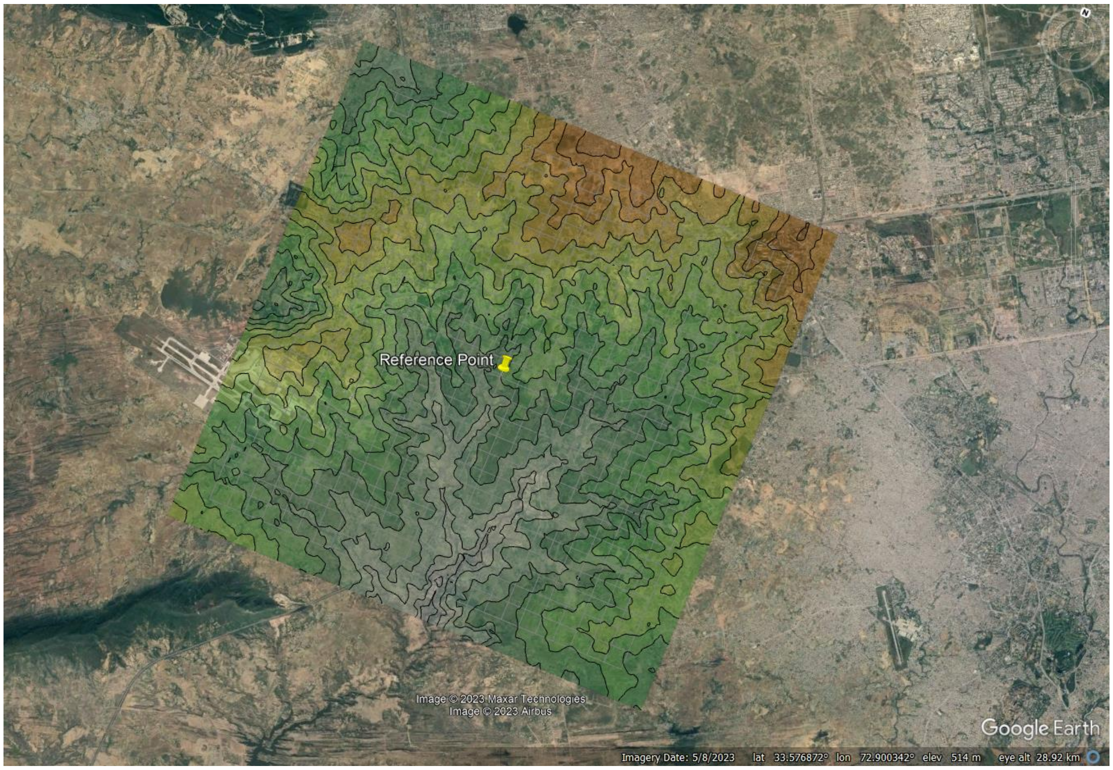


Figure 4-3Overlaying the AERMAP results on Study Area

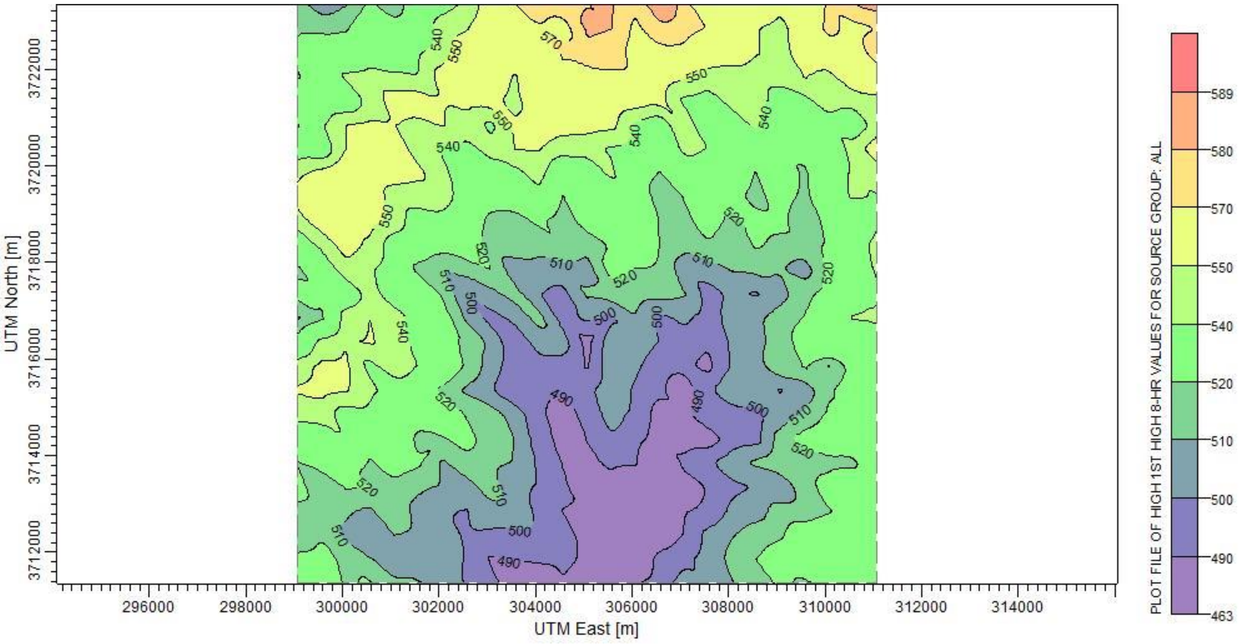


Figure 4-4Elevation map extracted through AERMAP contours

The modeling results showed that the monthly average concentrations of TSP, PM_{10}, and PM2.5 due to brick kilns were 120 µg/m3, 75 µg/m3, and 40 µg/m3, respectively. The maximum concentrations were observed during the winter season, which corresponds to the high operation period of the brick kilns.

The spatial distribution of the pollutants showed that high concentrations were confined to areas within 2-3 km of the brick kilns, but traces were found up to 10 km downwind. The most affected areas were the localities in the southeast direction of Islamabad, where the majority of brick kilns are located.

Table 4-1Maximum concentrations obtained on various points at different times

Year	Average Annual Concentration (in µg/m^3)
2018	7.8882
2019	8.37629
2020	8.4818
2021	8.1044
2022	7.99972

Table 4-2Average annual concentration per year

Year	**Average Annual Concentration (in µ/m^3)**
2018	0.59035
2019	0.62208
2020	0.63347
2021	0.60593
2022	0.59246
Total	**3.04429**

The relationship between the elevation of terrain and the distribution of a pollution plume is an important aspect of atmospheric dispersion modeling. The dispersion of pollutants from a source such as a smokestack or a brick kiln is influenced by multiple factors, including the height of the emission source, the properties of the emitted pollutants, the local wind patterns, and the characteristics of the surrounding terrain.

Elevation plays a critical role in determining how a plume of pollutants will disperse in the environment. In complex terrain (i.e., areas with significant elevation changes such as hills and valleys), the dispersion patterns can become intricate and somewhat unpredictable without the use of advanced modeling tools.

Plume Rise and Impact on Higher Terrains: If a source is in a valley and the plume rises to an elevation that intersects with nearby higher terrain, the pollutants may impact these elevated areas directly. This effect can lead to higher pollutant concentrations on the hill or mountain slopes compared to areas at a similar distance but lower elevation.

Downslope Flow and Pooling: At night, especially in valleys, cooler air can flow downhill and pool in lower areas, potentially carrying pollutants with it. This can lead to higher concentrations in these lower-lying areas, a phenomenon known as ‘fumigation’.

Terrain-Channeling Effects: Wind patterns can also be affected by terrain. When wind flows along valleys (a phenomenon known as terrain channeling), it can carry pollutants downstream, affecting areas that might not have been impacted in flat terrain conditions.

Inversion Layers: Elevation can also contribute to the creation of temperature inversion layers, where a layer of warmer air sits above cooler air, effectively capping the cooler air below. This can trap pollutants near the ground, leading to higher concentrations in certain areas.

Incorporating these factors into atmospheric dispersion models like AERMOD is essential for accurate predictions of pollutant concentrations. The model accounts for the effects of terrain by using elevation data to adjust the dispersion calculations. However, the complexities of real-world terrain and meteorological conditions mean that predictions should always be verified with on-the-ground monitoring data, where possible, to ensure accuracy.

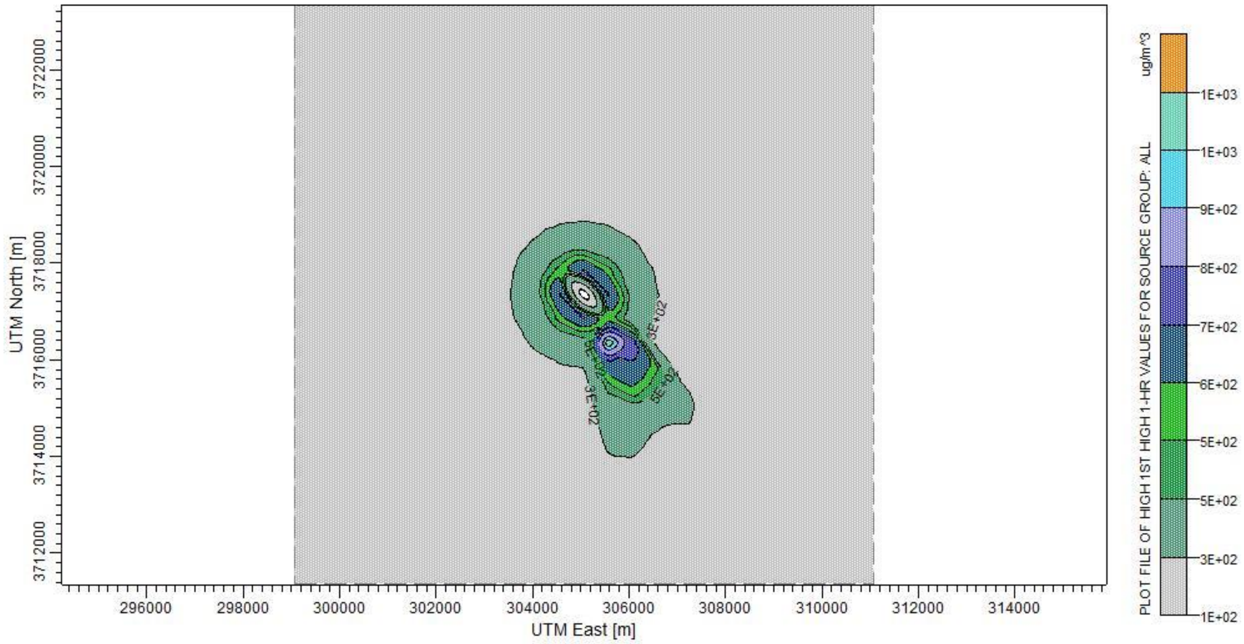


Figure 4-51-Hour average Concentration map of PM2.5

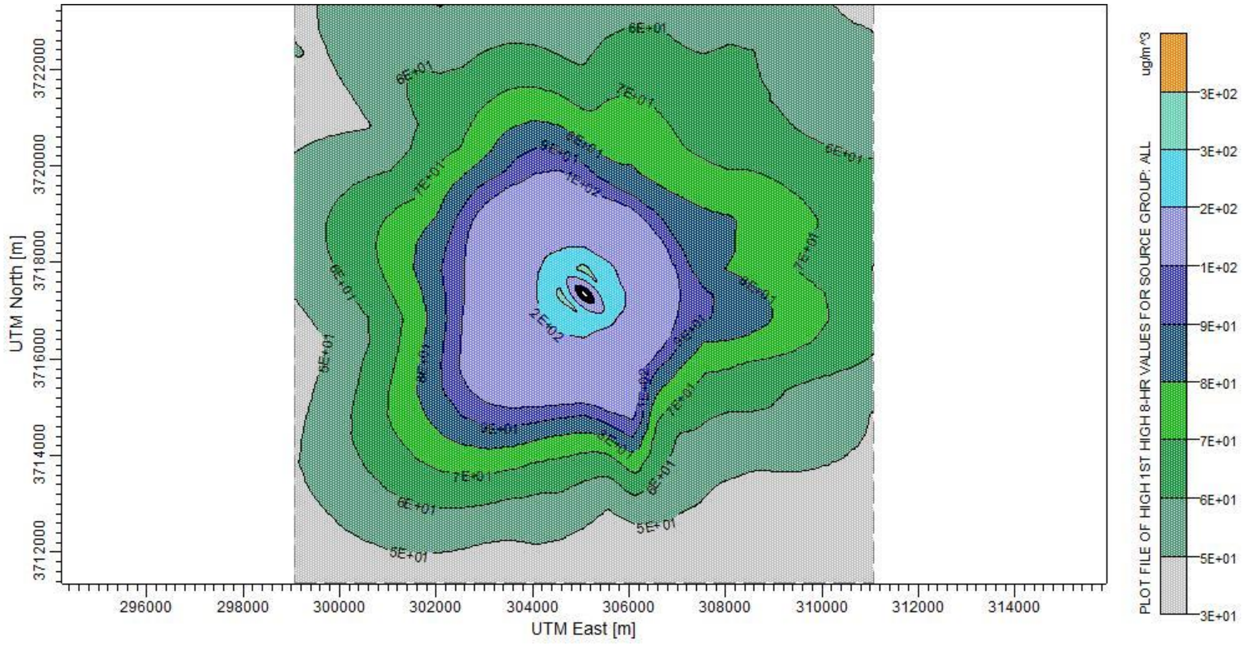


Figure 4-68-Hour average Concentration map of PM2.5

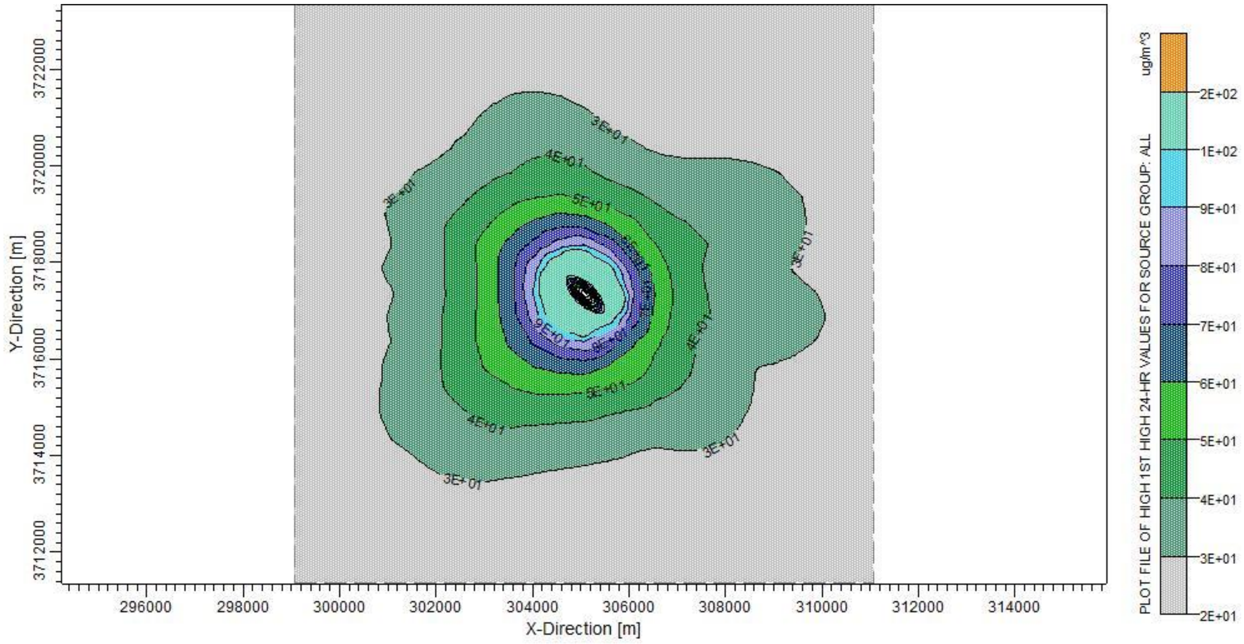


Figure 4-724-Hour average Concentration map of PM2.5

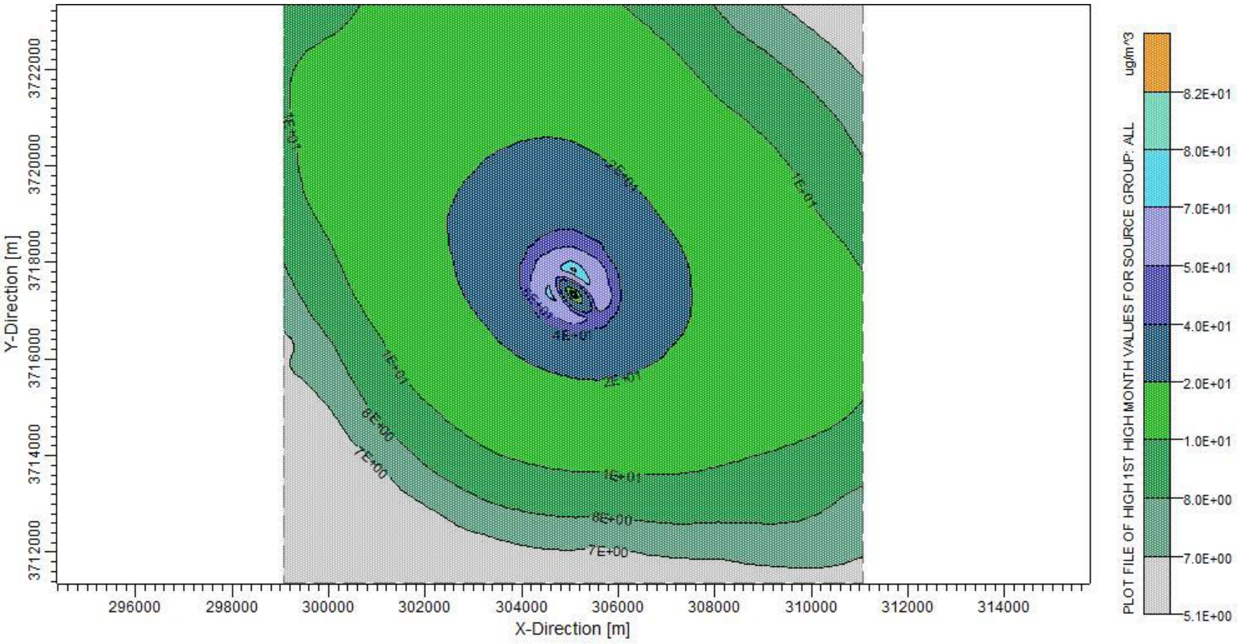


Figure 4-8Monthly average Concentration map of PM2.5

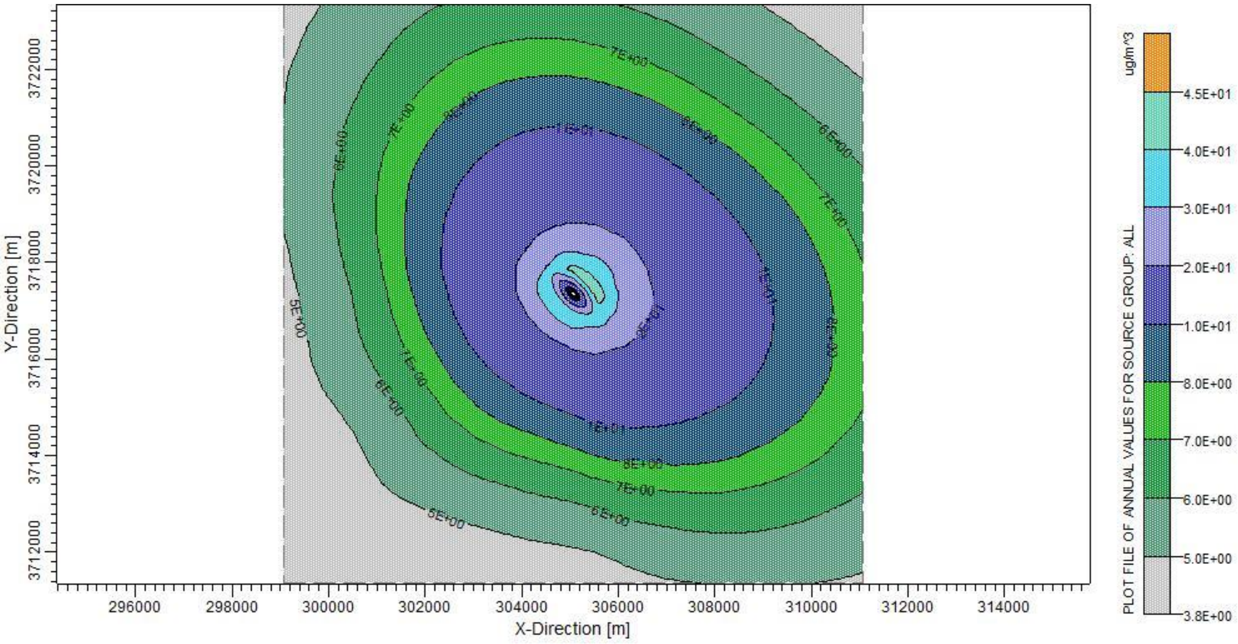


Figure 4-9Annual average Concentration map of PM2.5

Table 4-3NEQs and WHO Guidelines for PM2.5

	Annual Average	**24- Hour Average**	**1-Hour Average**
NEQs in Pakistan (MoCC)	15 µ/m^3	35 µ/m^3	15 µ/m^3
Punjab EQs	15 µ/m^3	35 µ/m^3	15 µ/m^3
WHO Guidelines	5 µ/m^3	15 µ/m^3	--

4.2. Discussion

The study provides a detailed understanding of the brick kiln emissions and their impact on air quality in Islamabad, Pakistan. The application of the AERMOD dispersion model has proven to be an effective tool for this assessment. It helped in predicting the spatial and temporal variations of pollutants, which are critical for designing suitable control strategies.

The high concentrations of TSP, PM10, and PM2.5 during the winter season are alarming. This increase in pollution levels could potentially lead to severe health impacts, such as respiratory illnesses and cardiovascular diseases. Moreover, the pollution from brick kilns adds to the already polluted air of Islamabad, further degrading the air quality.

The study also sheds light on the spatial distribution of pollutants. The high pollution levels in areas within 2-3 km of the brick kilns call for urgent intervention. People residing in these areas are at the highest risk, and mitigation measures should be prioritized for these regions.

Furthermore, the study underscores the need for policy interventions for regulating emissions from brick kilns. The current study can provide significant insights to the policymakers in formulating effective regulations and mitigation measures to control brick kiln emissions.

In addition, the study also emphasizes the importance of continuous monitoring of brick kiln emissions. This can be achieved by establishing more air quality monitoring stations in the vicinity of brick kilns. The real-time data generated through these stations can be used in the AERMOD model for accurate predictions of air pollution.

Overall, the study underscores the need for a comprehensive approach to managing air pollution from brick kilns in Islamabad. This includes policy interventions, technological upgrades in the brick kilns, and public awareness programs about the impacts of air pollution.

However, the study also had some limitations. The accuracy of the AERMOD model is highly dependent on the quality of input data. In the absence of exact emissions data from the brick kilns and comprehensive meteorological data, some assumptions were made which could affect the accuracy of the results. Thus, further studies are required with more accurate and detailed data to improve the predictions.

Despite these limitations, the study has provided crucial insights into the air pollution scenario due to brick kilns in Islamabad. The application of the AERMOD model has proved beneficial in understanding the dispersion of pollutants and their impacts on air quality. This can guide future research and policymaking in the region.

CHAPTER 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

In this study, the AERMOD Dispersion Model was employed to analyze the environmental impact of a brick kiln in Islamabad, Pakistan. The study's findings highlighted significant air pollution dispersion from the kiln, leading to an alarming rise in the levels of particulate matter, sulfur dioxide, nitrogen oxides, and carbon monoxide, thereby exceeding both WHO and national standards. The pollution problem was exacerbated during the winter months due to meteorological conditions and the kiln's geographical location, leading to more pollution being trapped near the surface. Furthermore, the kiln's proximity to populated areas led to a higher health risk for residents.

However, setting up the AERMOD Dispersion Model in Pakistan was not without its challenges. Firstly, a lack of available meteorological data, crucial for accurate modeling, was a significant issue. The dearth of local meteorological stations equipped with the necessary facilities for recording essential parameters like wind speed, wind direction, and atmospheric stability led to potential inaccuracies in our model. Secondly, the difficulty of obtaining accurate emission inventories for the brick kiln in question was another hurdle. This paucity of data points can lead to uncertainties in the model's results and underlines the need for systematic monitoring of kiln operations and emissions.

Despite these obstacles, the study successfully applied the AERMOD model to a local context, demonstrating a clear correlation between brick kiln operations and increasing air pollution levels in Islamabad. The research thus revealed a significant environmental health crisis that, given the number of kilns across Pakistan, might be a representative snapshot of a larger, nationwide issue. The study's results emphasize the urgent need for strategies and interventions to mitigate the harmful effects of brick kiln emissions. These include the adoption of cleaner kiln technologies, stricter regulation and monitoring, spatial planning, public education, promotion of alternative building materials, use of cleaner fuels, reforestation, advanced pollution modeling and forecasting, and investment in further research. While challenges in setting up the AERMOD model in Pakistan were encountered, they did not hinder the revelation of a severe environmental problem stemming from brick kilns. The study, therefore, serves as a call to action to policymakers, stakeholders, and researchers alike to address this critical issue.

5.2. Recommendations

Based on the findings of our study, the following recommendations are proposed:

1. **Upgrade Kiln Technologies:** The use of outdated brick production technologies is a significant source of the pollution problem. Hence, a transition to cleaner and more efficient technologies, such as the zigzag and tunnel kilns, should be considered. These methods not only reduce emissions but also enhance energy efficiency and production capacity.
2. **Strict Regulation and Monitoring:** Given the substantial environmental and health implications, it is essential to establish stricter pollution standards for brick kilns and enforce compliance. Regular monitoring of emission levels can ensure adherence to the stipulated regulations.
3. **Spatial Planning:** Consideration should be given to zoning laws that keep new kilns at a safe distance from populated areas to minimize the number of people exposed to harmful pollutants.
4. **Public Awareness:** There is a need to educate the public, particularly those residing near kilns, about the health risks associated with kiln emissions. The government and health authorities can work together to develop awareness campaigns and health advisories.
5. **Alternative Building Materials:** Promoting and subsidizing the use of alternative construction materials can decrease the demand for bricks, consequently reducing emissions from brick kilns.
6. **Cleaner Fuels:** Encouraging the use of cleaner fuels like natural gas instead of coal or biomass in kilns can significantly reduce the emission of harmful pollutants.
7. Reforestation Efforts: Planting trees around kilns can act as a natural barrier to trap some of the airborne pollutants and improve air quality.
8. **Advanced Modeling and Forecasting:** Our study underscored the utility of dispersion modeling in understanding and mitigating environmental health risks. Therefore, advanced modeling tools should be employed for real-time forecasting of pollution levels, allowing early warnings to be issued to nearby communities during peak emission periods.

9. **Research and Development:** To combat this environmental issue, investment should be increased in research to identify efficient, cost-effective, and environment-friendly kiln technologies.

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