Use of Air Dispersion modelling for the assessment of an air quality of an industrial area

Thesis submitted in partial fulfillment for the
requirement of degree of

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in
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Submitted By
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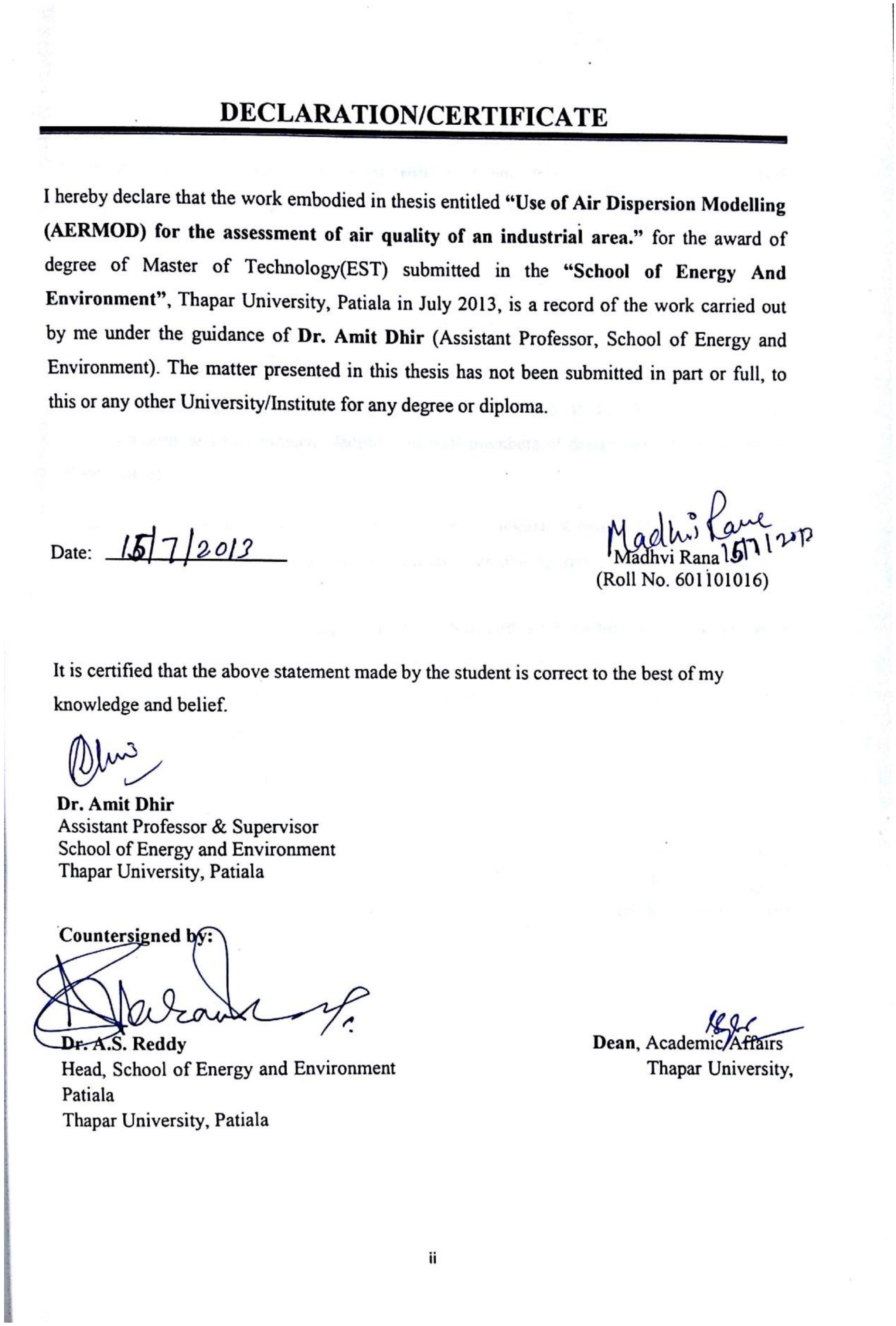

DECLARATION/CERTIFICATE

I hereby declare that the work embodied in thesis entitled **"Use of Air Dispersion Modelling (AERMOD) for the assessment of air quality of an industrial area."** for the award of degree of Master of Technology(EST) submitted in the **"School of Energy And Environment"**, Thapar University, Patiala in July 2013, is a record of the work carried out by me under the guidance of **Dr. Amit Dhir** (Assistant Professor, School of Energy and Environment). The matter presented in this thesis has not been submitted in part or full, to this or any other University/Institute for any degree or diploma.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

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ABSTRACT

For Gobindgarh town, out of total area of 9 sq. km. (2223acs.) 33.74% is occupied by industrial use. Air polluting industries in Mandi Gobindgarh are using coal /furnace oil as fuel in their furnaces emitting the aforesaid pollutants, besides the process/ fugitive emissions. In addition to this, burning of rice and wheat straw by the farmers in the agricultural fields surrounding Mandi Gobindgarh is also affecting the ambient air quality of the town. RSPM and SO_x pollutants belong to Group-B pollutants (organics probable Carcinogens), whereas NO_x is Group-A pollutant. The Exceedence Factor in regard to these pollutants has been observed to be more than 1.5 (critical pollution). The degradation in the quality of ambient air of Mandi Gobindgarh has taken place due to unplanned and improper development of the city. Therefore, a detailed study on emission sources and quantification of pollutant concentration by means of dispersion modelling is required to access the environmental impacts. On the basis of the predicted increments to air pollutant concentrations, an effective mitigation and environmental plan can be devised for sensitive areas. In this study 26 sampling sites were selected on the basis of major stacks in industrial area and types of industries. Stack monitoring campaign was carried out at periodic intervals, such as once every three months at the peak working hour of the industry through-out the study period of one year i.e. May 2012 to April 2013 to ensure proper representation of activities. The average emissions of SO_2 and NO_2 measured from representative stacks were taken to compile the emission inventory. The essential meteorological data like wind speed, wind direction, ambient air temperature, relative humidity, rainfall, atmospheric pressure, cloud cover, ceiling height and solar radiation were collected for daily mean hourly data through-out the study period with the help of Weather Monitoring Station and IMD, Patiala. Meteorological data then compiled in an excel file for further processing by AERMET and wind rose diagram and surface and profile file for the area has been generated. It was observed that the pre-dominant wind direction is from West with 59.87 % frequency of calm winds and the wind speed was 2.95 Knots. AERMOD was run for 1h, 24h and periodic average time to generate isopleths showing areas of minimal to high concentrations. In case of 1h average time for NO_2 emissions, highest concentration of 11.87µg/m^3 at receptor C (RIMT College) and lowest concentrations of 2.287µg/m^3 at D (PPCB) and F (Floating restaurant, picnic spot) respectively were predicted. In case of 24h average time for NO_2 emissions, highest concentration of 5.3µg/m^3 at receptor A, B and C (RIMT College, Ambe Majra and Ajnali respectively) and lowest concentrations of 0.3µg/m^3 and 0.1µg/m^3 at D

(PBCB) and F (Floating restaurant, picnic spot) were predicted. In case of periodic average time for NO_2 emissions, highest concentration of 1.43µg/m^3 at receptor C and B (RIMT College and Ambe Majra respectively) and lowest concentrations of 0.6µg/m^3, 0.6µg/m^3 and 0.02µg/m^3 at D (PPCB), F (Floating restaurant, picnic spot) and E (Chattarpur Zoo) respectively were predicted. But in this study only 10 % of the industrial emissions were covered. In case of 1h average time for SO_2 emissions, highest concentration of 0.451µg/m^3 at receptor A and lowest concentrations of 0.025µg/m^3 at D, B and F receptors were predicted. In case of 24h average time for SO_2 emissions, highest concentration of 0.20µg/m^3 at receptor A and lowest concentrations of 0.035µg/m^3 at E and C receptors were predicted. In case of periodic average time for SO_2 emissions, highest concentration of 0.0339µg/m^3 at receptor C and lowest concentrations of 0.002µg/m^3, 0.0017µg/m^3 and 0.004µg/m^{3}at E, D and F receptors were predicted. But in this study only 10 % of the industrial emissions were covered. Hence the actual emission scenario would be even worse than predicted from this simulation.

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CHAPTER 1

AIR QUALITY

1.1 Overview

Every day, the average person inhales about 20,000 litres of air. Every time we breathe, we risk inhaling dangerous substances that have found their way into the air .Air pollution includes all contaminants found in the atmosphere. These dangerous substances can be either in the form of gases or particles. Air pollution can be found both outdoors and indoors. Pollutants can be trapped inside buildings, causing indoor pollution that lasts for a long time. Air quality can be defined as a ‘measure of the degree of ambient atmospheric pollution, relative to the potential to inflict harm on the environment’. The concept of threat to public health is fundamental to this description and represents the driving motive behind current air quality research. The potential for deterioration and damage to both public health and the environment, through poor air quality, has been recognised at a legislative level, culminating in the establishment within the United Kingdom of the Environmental Protection Act 1991 *(Lane, 1995)* and the Environment Act 1995 *(Tromans, 1995).* The sources of air pollution are both natural and anthropogenic. As one might expect, humans have been producing increasing amounts of pollution as time has progressed and they now account for the majority of pollutants released into the air. Air pollution has been a problem from the many decades. The effects of air pollution are diverse and numerous. Because it is located in the atmosphere, air pollution is able to travel easily. As a result, air pollution is a global problem and has been the subject of global cooperation and conflict.

Increasing urban air pollution due to the continuous growth of industries and vehicular traffic has given rise to a need for comprehensive monitoring accompanied by modelling of air quality. It is not always feasible to monitor/measure the concentrations of species at various vulnerable points of a particular area due to high cost and the experimental difficulties involved. In most of the 23 Indian cities with a million-plus population, air pollution levels exceed World Health Organization’s (WHO) recommended health standards. A study conducted by the World Bank indicates premature deaths of people in Delhi owing to high levels of air pollution *(CPCB, 2003)*. Therefore, there is a need for timely information about changes in the pollution level.

1.2 Air quality status in India

The rate at which urban air pollution has grown across India is alarming. A vast majority of cities are caught inextricably in the toxic web as air quality fails to meet health-based standards. Almost all cities are reeling under severe particulate pollution while newer pollutants like oxides of nitrogen and air toxics have begun to add to the public health challenge. The air quality monitoring program in India was started in 1967 by the National Environmental Engineering Research Institute (NEERI) (then named CPHERI, Central Public Health Engineering Research Institute).The monitoring was expanded to include regular monitoring at three stations in 1978. The CPCB initiated the National Ambient Air Quality Monitoring (NAAQM) program in the year 1984 with seven stations at Agra and Anpara. Subsequently, the program was renamed as National Air Monitoring Programme (NAMP). The number of monitoring stations under the NAMP has increased, steadily as shown in Figure 1.1. Under NAMP, four air pollutants, viz., sulphur dioxide (SO_2), oxides of nitrogen as NO_2 and suspended particulate matter (SPM) and respirable suspended particulate matter ($RSPM/PM_{10}$), have been identified for regular monitoring at all the locations. Besides this, additional parameters such as respirable lead and other toxic trace metals, hydrogen sulphide (H_2S), ammonia (NH_3) and polycyclic aromatic hydrocarbons (PAHs) are also being monitored in 10 metro-cities of the country since 1990.

Figure 1.1: Growth in number of stations under operation in NAM *(Source: CPCB, 2012)*

The air quality terms is expressed in terms of low, moderate, high and critical for various cities/towns that have been monitored. The concentration ranges for different levels have been selected based on the Notified Standards for different pollutants and area classes by calculating an Excedence Factor (the ratio of annual mean concentration of a pollutant with that of a respective standard) *(PPCB,2010)*.The four air quality categories are Critical pollution (C) when EF is more than 1.5; High pollution (H): when EF is between 1.0 - 1.5; Moderate pollution (M): when EF between 0.5 - 1.0; and Low pollution (L): when EF is less than0.5.

It is clear from the above categorization, that the locations in either of the first two categories are actually violating the standards, although, with varying magnitude. Those, falling in the third category are meeting the standards as of now but likely to violate the standards in future if pollution continues to increase and is not controlled. However, the locations in Low pollution category have a rather pristine air quality and such areas are to be maintained at low pollution level by way of adopting preventive and control measures of air pollution. The pollution control classification and annual average concentration in States and UTs of India are given in Table 1.1 and Figure 1.2 respectively.

Table 1.1: Pollution level classifications *(Source: CPCB, 2012)*

Pollution level	Annual mean concentration range (μg/m^3)					
	Industrial, Rural, Residential & others areas			Ecologically sensitive area		
	SO_2	NO_2	PM_{10}	SO_2	NO_2	PM_{10}
Low(L)	0-25	0-20	0-30	0-10	0-15	0-30
Moderate(M)	26-50	21-40	31-60	11-20	16-30	31-60
High(H)	51-75	41-60	61-90	21-30	31-45	61-90
Critical(C)	>75	>60	>90	>30	>45	>90

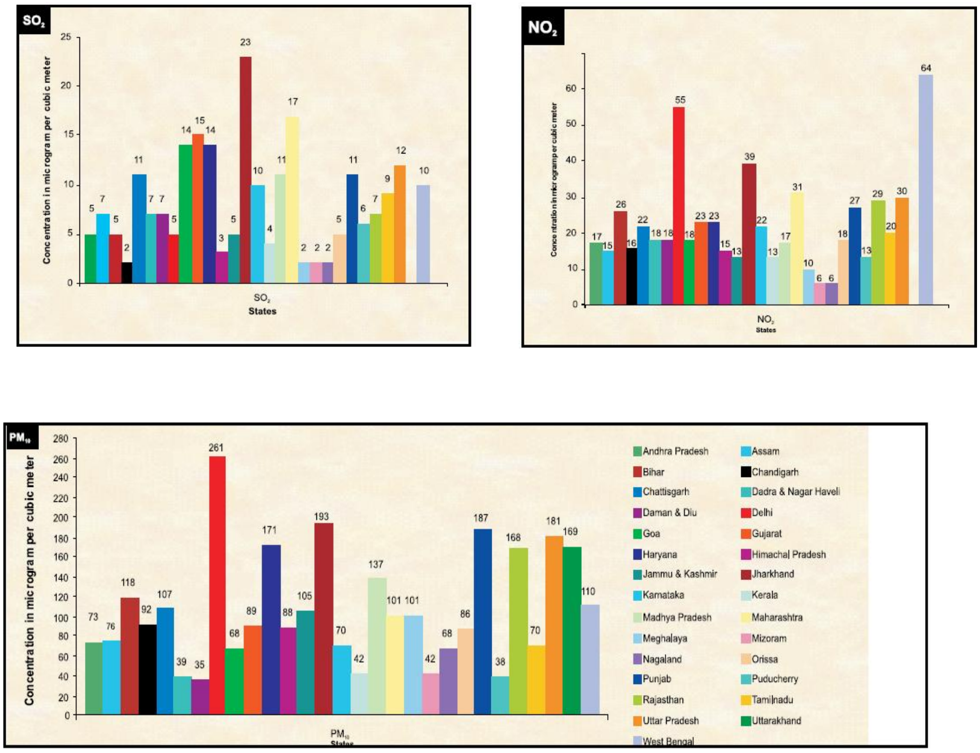


Figure 1.2: Annual average concentration in States and UTs of India

(Source: CPCB, 2012)

1.3 Air pollution affected areas in India

Air pollution in India is mainly caused mainly by vehicles, industrial, agricultural and domestic sources. It is mainly concentrated in the following four areas:

(i) Major cities: The problem of air pollution is in major cities where the prominent sources are vehicles and small- and medium-scale industries. These cities include Delhi, Kolkata, Mumbai, Chennai, Ahmedabad, Bangalore, Hyderabad, Pune, Kanpur, etc.

(ii) Critically polluted areas: In India, there are as many as 24 areas which have been designated as ‘Critically Polluted Areas’ with respect to air and water pollution by CPCB. These areas are given in Table 1.2.

Table 1.2: Areas having pollution problem in India *(Source: CPCB, 2003)*

S.No.	Problem Areas in India	Problem Area Type of Industry
1	Singrauli	Power Plants, Mining, Aluminium Industry
2	Korba	Power Plants, Aluminium Industry, Mining
3	Vapi	Chemical Industries
4	Ankaleshwar	Chemical Industries
5	Greater Cochin	Oil Refineries, Chemical, Metallurgical Industries
6	Visakhapatnam	Oil Refinery, Chemical, Steel Plants
7	Howrah	Foundry, Rerolling Mills
8	Durgapur	Chemical Industries, Power Plants, Steel Plants
9	Manali	Oil Refineries, Chemical Industry, Fertilizer Industry
10	Chembur	Refineries, Power Plant, Fertilizer Industry
11	**Mandi Gobindgarh**	**Secondary Steel Industry**
12	Dhanbad	Mining, Coke Oven
13	Pali	Cotton Textile, Dyeing
14	Nagafgarh	Drain Basin Power Plants, Vehicles
15	Angul-Talcher	Mining, Aluminum Plants, Thermal Power Plants
16	Bhadravati	Iron and Steel, Paper Industry
17	Digboi	Oil Refinery
18	Jodhpur	Cotton Textile, Dye
19	Kala-Amb	Paper, Electroplating
20	Nagda-Ratlam	Viscose Rayon, Caustic, Dyes, Distillery
21	North Arcot	Tanneries
22	Parwanoo	Food Processing Unit, Electroplating
23	Patancheru – Bollaram	Organic Chemical, Paints Petrochemical Industry
24	Tarapur	Chemical Industry

(iii) Rural areas: Indoor air pollution exists in rural areas with domestic fuel as the main source of air pollution. In rural areas, cow dung and wood sticks are used as fuel in household. Kitchens are without any proper ventilation, resulting in the build-up of air pollutants in the houses. Indoor air pollution exists in rural areas due to lack of proper ventilation and absence of exhaust fans/ electric chimneys.

(iv) Seasonal areas: 'Agricultural stubble burning' or 'crop stubble burning' is one of several types of prescribed biomass burning. Agricultural stubble burning produces broad area emissions of smoke, particulates, breakdown products, dioxins and associated odour. Burning may also involve the release of pesticides and herbicides that have been used on the crops to be burnt. Burning straw is considered a low-cost solution alternative to tilling in the straw. Under such circumstances, farmers may have no choice but to burn the straw. During harvesting the emissions in the atmosphere increases abruptly along with the industrial emissions.

1.4 Description of study area and its Air quality

Mandi Gobindgarh is a town and a municipal committee in Fatehgarh Sahib District in the Indian state of Punjab and also known as 'Steel Town of India'. The dominant industries includes 89 induction furnaces, 38 cupola furnaces, 1 arc furnace, 247 steel rolling mills, 13 refractories and forging industry each and 3 lead extraction units. It stands the 17th most polluted industrial town in India. (The Tribune India: 9 Dec 2011) and is one among the list of critically polluted industrial hubs of the country on which the ministry had imposed a moratorium. (Indian Express: 09 Dec 2012). This town is located on National Highway-I. Geographically, Mandi Gobindgarh lies between north latitude $30^{o}37'30''$ and $30^{o}42'30''$ and east longitude $76^{o}15'$ and $76^{o}20'$. It shares common boundaries with several districts such as Mohali, Patiala, Ludhiana and Rupnagar, and is well connected by rail and road. For Gobindgarh town, out of total area of 9 sq. km. (2223acs.) 33.74% is occupied by industrial use, 31.49% by residential use, 13.68% by traffic & transportation and 10.66% by agriculture and accommodates a population of 60,677 as per 2001 census and the expected population upto 2009 was 76,677 *(PPCB, 2010).*

As per the inventory prepared by the CPCB, there are 510 (i.e. 404 in Mandi Gobindgarh & 106 Khanna area) air polluting industries in Mandi Gobindgarh which are using coal /furnace oil as fuel in their furnaces emitting the aforesaid pollutants, besides the process / fugitive emissions. In addition to this, burning of rice and wheat straw by the farmers in the agricultural fields surrounding Mandi Gobindgarh is also affecting the ambient air quality of the town. The degradation in the quality of ambient air of Mandi Gobindgarh has taken place due to unplanned and improper development of the city. The CEPI score for Mandi Gobindgarh has been observed to be 75.08 by PBCB *(PBCB, 2010)* which is cumulative score of the environment pollution index calculated for the Air (62.0), Water (55.50) and Land (62.0), separately. RSPM and SO_x pollutants belong to Group-B pollutants (organics probable Carcinogens), whereas NO_x is Group-A pollutant. The Exceedence Factor in regard to these pollutants has been observed to be more than 1.5 (critical pollution).

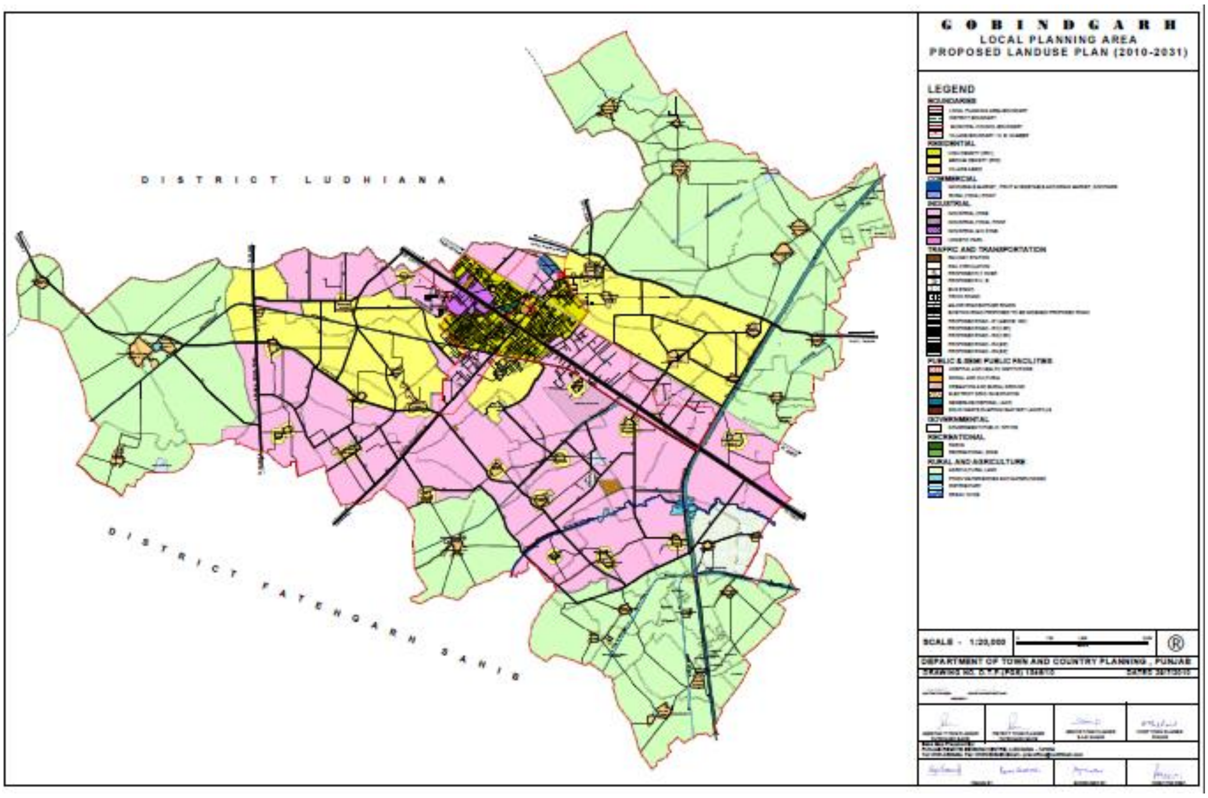


Figure 1.3: Master plan image of Mandi Gobindgarh *(Source: www.puda.nic.in)*

The environment of Mandi Gobindgarh has degraded a lot during the last few years due to rapid urbanization, industrialization, increase in population, vehicles and commercialization of land available within the town. This increase in pollution of Mandi-gobindgarh has huge impact on the air quality of nearby historical places like Fatehgarh Sahib, Chandigarh, Patiala(11km,58km and 48km respectively from Mandi-Gobindgarh). The main stationary sources of air pollution are the industrial units, which are emitting particulate matter, sulphur di-oxide and oxides of nitrogen etc. The Punjab Pollution Control Board has identified following 6 industrial clusters within the jurisdiction of critically polluted area of Mandi Gobindgarh shown in Table 1.3.

Table 1.3: Clusters identified as critically polluted area of Mandi Gobindgarh *(Source: PBCB, 2010)*

Cluster No.	**Name of the industrial cluster**
I	Area near RIMT starting from M/s Cold Drip Pvt. Ltd. to M/s JTG Alloys Ltd.
II	Area between RIMT road (upto M/s Pushpanjali Steel) to Talwara Road (upto M/s M.R. Alloys) on one side of G.T. Road and upto Rajwaha on the other side of the G.T. Road
III	Area on G.T. Road (right side - Rajpura to Ludhiana) covered between M/s IMT, M/s Gian Steel Rolling Mills, M/s Baba Balak Nath Steel Rolling Mills, M/s Bansal Iron and Steel Rolling Mills (on left side) and area starting from M/s Patiala Casting to M/s Bansal Iron upto Rajwaha.
IV	Area bound between M/s Gopal Mills, M/s Kailash Steel Rolling Mills, M/s Northern India Pvt. Ltd. and M/s Aarti Strips in Guru Ki Nagri
V	Area on both sides of Amloh Road covered between M/s Doaba Steel Rolling Mills, M/s Janta Steel & Agro Industries, M.C. disposal point, M/s Vishnu Steels and M/s R.K. Steel and Allied Industry
VI	Area on both sides of G.T. Road on Khanna side starting from M/s Ganesh Steel Industry to M/s Karam Steel to M/s Shri Ganesh Steel Rolling Mills to M/s Dhiman Steel Industry to M/s M.T.C. Steel Industry to M/s Kumar Hammer and Model Town.

CHAPTER 2

MODELLING

2.1 Introduction

Air quality modelling is a numerical tool using the causal relationship between emissions, meteorology, atmospheric concentrations, deposition, and other factors. Air quality measurements give important, quantitative information about ambient concentrations and deposition, but they can only describe air quality at specific locations and times, without giving clear guidance on the identification of the causes of the air quality problem. Air quality modelling, instead, can give a more complete deterministic description of the air quality problem, including an analysis of factors and causes (emission sources, meteorological processes, and physical and chemical changes), and some guidance on the implementation of mitigation measures. The principal application of air quality modelling is to investigate air quality scenarios so that the associated environmental impact on a selected area can be predicted and quantified.

Pollutants are continuously released from numerous sources into the atmosphere. The pollution sources could be point sources (e.g., stacks or vents), area sources (e.g., landfills, ponds, storage piles), or volume sources (e.g., conveyers, structures with multiple vents). The dispersion of the pollutants in the atmosphere emitted from these sources depends on source characteristics (emission rate of pollutant, stack height, exit velocity of the gas, exit temperature of the gas, stack diameter) and meteorological conditions (wind velocity, wind direction, ambient temperature, atmospheric stability and cloud cover). Air quality models, when combined with emissions inventory and meteorological data, can be used as part of risk assessments that may lead to the development and implementation of regulations or voluntary reduction measures. Air quality models are the only method that quantifies the deterministic relationship between emissions and concentrations/depositions, including the consequences of past and future scenarios and the determination of the effectiveness of abatement strategies. This makes air quality models indispensable in regulatory, research, and forensic applications.

There are a wide range of models available, and it is important to select the model that meets the requirements of the task. No single model can handle all situations and range of applications. Models differ in the size of area that can be modelled and the number of situations that can be addressed. A model may be designed to handle only a single source, e.g., well test flare; multiple sources, e.g., a facility that has a flare stack, heaters and boilers; or combined sources, e.g., more than one facility and emission sources. Simpler models may deal with only two-dimensional transport by winds assuming the material emitted into the parcel stays at the same level, while more complex models may include 3-dimensional chemical and thermodynamic processes such as aerosol formation, convection, and turbulent diffusion. The overall accuracy and precision of results determined by a model is generally proportional to the complexity of the model, which in turn affects input data requirements and overall resources. The basic components of an air quality modelling system are given in below Figure 2.1.

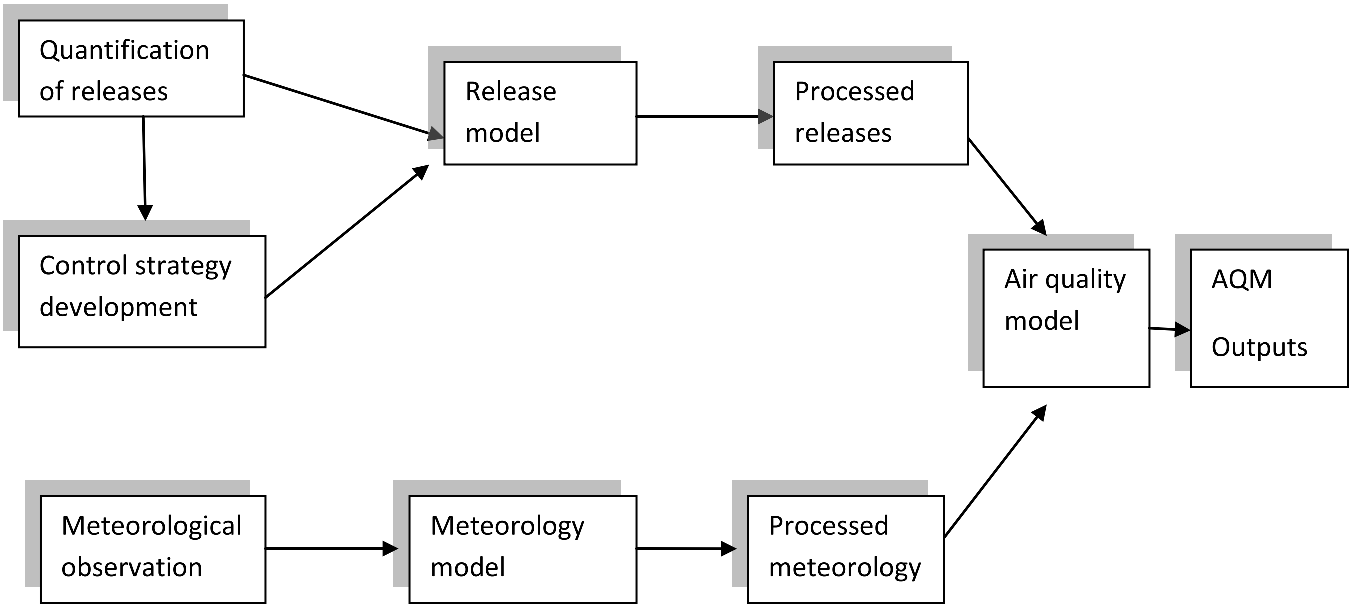


Figure 2.1: Basic components of an air quality modelling system *(Source: www.epa.gov)*

2.2 History

The modern science of air pollution modelling began in the 1920's when military scientists in England tried to estimate the dispersion of toxic chemical agents released in the battlefield under various conditions. This early research is summarized in the groundbreaking textbook by Sutton (1953). Rapid developments in the 1950's and 1960's, including major field studies and advances in the understanding of the structure of the atmosphere, led to the development of the first regulatory air quality models in the U.S. The textbooks by Pasquill (1974) and Stern (1976) review much of the research and theory up until the mid 1970's. However, the proliferation of air pollution research and models to date has made it necessary to read specialized journals and conference proceedings to keep up with developments.

2.3 Classification of models

In general, air quality models can be categorized as one of two types: **steady state** and **non-steady state** models. The movement of mass away from the source (i.e., advection) and turbulent diffusion (e.g., dispersion) are modelled in both types of models.

Steady-state models are models which assume no time-varying processes occur over the period of interest. Hence, material released travels infinitely in only one direction over the time period (e.g., one hour). Often, these models assume that the material is distributed normally (also termed a "Gaussian distribution") and are thus called "Gaussian plume" models. The steady-state model typically uses meteorological information obtained near the source and assumes it holds true throughout the modelling region (e.g., a 50 kilometre radius). This type of model is most widely used for stationary sources and for non-reactive pollutants (although models can take into account deposition and simple linear decay). Examples of steady models are Screen 3, ISCST 3, and CALINE3.

Non-steady state models are models which can simulate the effects of time- and space varying meteorological conditions on pollutant transport, transformation, and removal. These models are often used for chemically reactive pollutants or where there is complex topography or meteorology (e.g., complex sea breeze circulation). They requires complex wind flow characterization and other detailed meteorological information for dispersion. For chemical transformation, they require information on the important chemical compounds as well as chemical kinetics to properly characterize the transformation and removal of air toxics. These models often take the form of grid models with the calculation of the physical and chemical processes taking place at each grid location. Other model types include "puff models", which use a series of overlapping puffs to represent emissions. Examples of non steady models are CALPUFF, UAM-TOX.

Dispersion models are used to estimate or to predict the downwind concentration of air pollutants or toxins emitted from sources such as industrial plants, vehicular traffic or accidental chemical releases. It is based on source emission inventory and meteorological data validated by ambient data and can determine contributions of individual sources at any receptor in the airshed. Such models are important to governmental agencies tasked with protecting and managing the ambient air quality. The models are typically employed to determine whether existing or proposed new industrial facilities are or will be in compliance with the National Ambient Air Quality Standards (NAAQS). The models also serve to assist in the design of effective control strategies to reduce emissions of harmful air pollutants.

Receptor models are source-apportionment model used to estimate the relative impact of specific types of sources at a designated location (i.e., a receptor). Chemical and physical characteristics of gases and particles that are measured at the source and receptor are used both to identify the presence of and to quantify source contributions to receptor concentrations. The primary assumption of source-apportionment models is that each type of source is associated with a unique combination of pollutants (fingerprint for that source) that are measured in the ambient air. Examples include gasoline evaporation, diesel truck exhaust, tanker engine exhaust, and painting. In addition to the source fingerprints, monitoring results are used for one ambient monitoring location. Pollutants that are used in characterizing the sources must be measured in the ambient air. Two cautions apply to source-apportionment models. First, speciated data are required for source apportionment modelling; measurements of total mass for particles or total hydrocarbons are insufficient. Second, the species used in characterizing the sources either should not participate in atmospheric chemistry or should have very long lifetimes in the atmosphere. That is, this method does not work well when the source characteristics vary with time in the atmosphere, which is equivalent to changing over distance, or when the pollutants involved react with other pollutants in the atmosphere. Examples of source-apportionment models are Chemical Mass Balance model (CMB), Unmix, Positive Matrix Factorization (PMF).

2.4 Spatial classification of models

The predictive models discussed in this section are categorised by applicable spatial scale. It is convenient to consider three spatial scales: local, meso to regional, and global *(Reid et al., 2003).*

2.4.1 Local scale

Local scale modelling is typically used to assess the impact of single sources, or small groups of sources, over distances ranging up to tens of kilometres. Typically the pollutants are emitted from a stack, with an initial velocity, and at a temperature which is generally above that of the ambient air. Under the combined effect of the exit velocity and the buoyancy due to its elevated temperature, the plume rises above the stack top, before being bent over, and transported or advected by the wind. Turbulent eddies in the atmosphere spread the plume out in the horizontal and vertical directions. This dispersion leads to dilution of the pollutant as the plume travels downwind. The process is typically modelled by assuming a Gaussian concentration shown in equation 1 distribution in the horizontal and vertical directions. The resulting concentration is then given by:

$$C(x,y,z) = \frac{Q}{2\pi V \sigma_z \sigma_y} \exp\left[\frac{-y^2}{\sigma_y{}^2}\right] \exp\left[\frac{-z^2}{\sigma_z{}^2}\right]. \quad \text{………………… equation 1}$$

Where, C = concentration at point x, y, z; x = distance along plume centre line; y = horizontal distance from plume centre line; z = vertical distance from plume centre line; Q = emission rate; V = wind speed; σ_y, σ_z = dispersion coefficients in the y and z directions.

Because the distance and time scales considered are short, chemical or physical transformation of the pollutants modelled is almost never included in these models. Many variations are employed to treat more complex situations, including: multiple sources; impaction of the plume on the ground, or its confinement by topography; special behaviour under certain stability or boundary layer conditions, e.g., fanning, looping, fumigation, etc. and the effect of buildings on plume behaviour. A special case of the short term models is in their application in emergency situations, where they are applied in the case of a pollutant leak or discharge of any type.

2.4.2 Mesoscale to Regional Scale

Mesoscale to regional scale models consider spatial scales ranging from a few hundred to a few thousand kilometres. Mesoscale is itself subdivided as meso-gamma (0 to 20 km), meso-beta (0 to 200 km) and meso-alpha (0 to 2000 km). Mesoalpha overlaps with what is usually considered regional scale (up to three or four thousand kilometres). Up to ten or fifteen years ago it was usual to consider mesoscale separately from regional scale, a separation imposed by limitations in the science of modelling and in computer capability. Advances in both make it now possible and convenient to consider both scales together. There are two major types of regional scale models Lagrangian models and Eulerian models.

Lagrangian model are dispersion model mathematically follows pollution plume parcels (also called particles) as the parcels move in the atmosphere and they model the motion of the parcels as a random walk process. Model then calculates the air pollution dispersion by computing the statistics of the trajectories of a large number of the pollution plume parcels. A Lagrangian model uses a moving frame of reference as the parcels move from their initial location. It is said that an observer of a Lagrangian model follows along with the plume.

Eulerian model is similar to a Lagrangian model in that it also tracks the movement of a large number of pollution plume parcels as they move from their initial location. The most important difference between the two models is that the Eulerian model uses a fixed three-dimensional cartesian grid as a frame of reference rather than a moving frame of reference. It is said that an observer of an Eulerian model watches the plume go by.

2.4.3 Global scale

As the name implies, global models consider the transport of pollutants throughout the atmosphere, with no artificial restriction of the domain. Many or most current use global models are Eulerian in formulation; GRANTOUR is a Lagrangian exception. The large spatial extent of these models dictates that the spatial resolution (grid spacing) must be relatively coarse to keep the computational demands within reasonable bounds. To date, most global modelling has been confined to carbon dioxide and the climate change issue, which also means that chemical transformation, is not treated, further streamlining the computation.

2.5 Data Required for Dispersion Modelling

Depending on the level of refinement of the model, the required input data for an air quality model will include (but not necessarily be limited to) the following parameters. Meteorology, terrain, and emissions data are processed and used as primary input data for air quality models.

i) Emission rate- is the rates at which emissions are released into the atmosphere are specified as a rate of release for each chemical in units of mass per unit time.

ii) Physical/chemical characteristics of emissions- these data are closely related to emission rate. For some models, the phase of emission must be specified (e.g., gas, particulate, or semi-volatile). For chemicals present as particulate matter or as semi-volatile substances, particle size distribution and fraction of particle phase as a function of temperature, for each chemical, may be necessary inputs. In some cases, information may only be available on the basis of total volatile organic compounds or total particulates. This information may be speciated based on the emissions source type through the use of sources such as EPA’s SPECIATE database.

iii) Type of release point- the required input data, modelling approach, and model selected for assessment can depend on the type of release being modelled.

Point sources are releases from stacks and isolated vents, and typically have plume rise associated with the release due to the buoyancy or momentum of the effluent.

Area sources are sources which are usually low level or ground level releases with no plume rise (e.g., fugitive emissions from the summary of equipment leaks across a facility; uncontrolled emissions that escape from the windows along a building wall; releases of dust from a road or work site; slag dumps; storage ponds).

Volume sources are releases that are modelled as emanating from a 3-dimensional volume (such as a box). Examples include releases from conveyor belts or the collective releases from the gas pumps at service stations. Volume sources differ from area sources in that they have a vertical dimension to their release. Like area sources, they do not have plume rise.

Line sources are releases that are modelled as emanating from a two-dimensional area. Examples include rail lines and roadway segments. Line sources differ from area sources in that they have aspect ratios (length to width) much higher than 10:1. Like area sources, they do not have plume rise.

Specialized release types include multiple parallel release lines that result in increased buoyant dispersion (e.g., coke ovens, aluminium smelters); dense gas release; and exothermic gas release, jet-plume release and horizontal venting that may be defined and modelled using special techniques or models depending on the characteristics of the emission source.

iv) Release point parameters- depending on the type of source being modelled, the user may need to specify the physical characteristics of the release point. Key parameters may include the following:

- Release height above ground level (e.g., stack height, average height of fugitive emissions).
- Area of the release point (for point sources, stack diameter; for area sources, length and width of the area across which releases occur).
- Other stack parameters of the release stream for point sources that can alter the effective release height, which include temperature, stack orientation, the presence of obstructions to flow (i.e., rain caps), and exit velocity or flow rate. Flow rate is expressed in terms of the total volume of material released per unit of time.
- Facility building dimensions, if building downwash (i.e., the effects on plume dynamics due to structures located near the source) is modelled.

v) Location of special receptors -the location of known sensitive receptors (e.g., a school or day-care centre) may be a critical input when determining where to model ambient concentrations. If these special receptor locations are not identified, the model will only provide concentration estimates at the nodes of the modelling grid that is initially laid out around the source.

vi) Information on the surrounding land-use and terrain heights-for dispersion models, classification of the surrounding area as urban or rural is usually required (this classification can affect the rate of dispersion). In addition, more refined modelling that takes into account complex terrain (e.g., ground surfaces higher than release height elevation) will require terrain elevation data.

vii) Chemical-specific data-if transformation/removal is being modelled, rates of transformation or removal for the chemicals being modelled are required.

viii) Boundary or background concentrations- ideally, emissions from modelled source(s) are responsible for the modelled concentrations. However, background concentrations, or boundary conditions in the case of grid models, may be important contributors to the total concentrations. This is particularly relevant where modelled concentrations are compared to observed concentrations. There are three basic approaches to estimating background concentrations: default values based on supporting documentation from the literature (this is the simplest approach); data collected from monitoring stations within the study area; and estimates made from larger regional scale models that cover the study area. For grid type models, users should be aware that with a smaller modelling domain, there is more potential for the boundary concentrations to play a more important role in determining the total concentration.

2.6 Selection of model

The selection of a model for a specific application depends on a number of factors, including:

- The nature of the pollutant (e.g., gaseous, particulate, reactive, inert).
- The meteorological and topographic complexities of the area of concern.
- The complexity of the distribution of sources (point, area, volume).
- The spatial scale and temporal resolution required for the analysis.
- The level of detail and accuracy desired for the study and the amount of uncertainty that the analyst/risk manager is willing to accept and the technical expertise of user.

Applicability of different models vary with different conditions as shown in Table 2.1

Table 2.1: Discuss the applicability of different models for different conditions *(Source: www.epa.gov)*

Modelling Attribute	SCREEN3	ISCST3	ISCLT3	AERMOD	ASPEN	CALPUFF	UAM-TOX
Point	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Volume	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Area	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Meteorology	Built-in worst case Meteorology	Hourly (NWS)or site specific equivalent	Frequency array of meteorological data	Hourly (NWS) or site specific equivalent	Multiple hourly observations (NWS) or site specific equivalent	Hourly user defined 3D fields, usually from a meteorological model with multiple meteorological stations	Hourly user-defined 3-D fields, usually from a meteorological model with multiple meteorological stations
Wet Deposition	No	Yes	No	Yes	Yes	Yes	Yes
Dry Deposition	No	Yes	Yes	Yes	Yes	Yes	Yes
Complex Terrain	Yes	Yes	No	Yes	No	Yes	Yes
Overwater Effects	No	No	No	No	No	Yes	No
Vertical Wind Shear	No	No	No	Yes	No	Yes	Yes
Building Downwash	Yes	Yes	Yes	Yes	Yes	Yes	No
Model Formulation and Plume Distribution	Steady-state, Gaussian	Steady-state, Gaussian	Steady-state, Gaussian sector average	Steady-state Gaussian stable & neutral conditions, bi-Gaussian in unstable conditions	Steady-state, Gaussian sector average	Non-steady-state, Gaussian puff	Non-steady-state grid model
Chemical Transformation	None	Simple decay	Simple decay	Simple decay (SO_2)	Difference between precursor inert and precursor decay	Simple pseudo first-order effects	Complete chemical mechanism for most gas-phase toxics
Relative Complexity	Simple	Moderate	Moderate	Moderate	Moderate	Complex	Complex

2.7 Model validity and accuracy

A fundamental requirement for the use of models in policy is that their predictions be credible. The term validation is commonly used interchangeably with verification, indicating that model predictions are consistent with observations. Validation is also used to suggest that a model is an accurate representation of physical reality. Policy-makers will look to see if models have been verified or validated. The differences between evaluation and verification or validation are important *(Oreskes et al., 1994)*, particularly in the context of air quality modelling. Full model evaluation and validation include a thorough peer review of the science of the model; evaluation of the model's ability to predict concentrations of the pollutant of interest, by comparing predictions against measurements; comparison of the performance of two or more models; more detailed evaluation of the ability of the model to predict correctly the concentrations of other chemical species involved in the chemical scheme. It is important to note that there is a fundamental limitation to how well models can be expected to replicate measurements. Accuracy of the model prediction depends upon accuracy of the input data used. The data collected always might not be accurate and this deviate model results from actual measured concentrations. A model predicts concentrations averaged over a certain volume, whereas measurements are made at a point.

CHAPTER 3

REVIEW OF LITERATURE

Increasing air pollution levels due to rapid urbanization and growth in industrial emissions are now causes of major concern in many large cities of the world. When strategies to protect public health are under consideration, establishing ambient air quality standards and regulations have been introduced in order to set limits on the emissions of pollutant. To achieve these limits, consideration was given to mathematical and computer modelling of air pollution. Therefore, air quality models are indispensable tools for assessing the impact of air pollutants on human health and the urban environment. The necessity for such models has increased tremendously especially with the rising interest in the early warning systems in order to have the opportunity to take emergent and preventive action to reduce pollutants when conditions that encourage high concentrations are predicted. On the other hand, long-term forecasting and controlling of air pollution are also needed in order to prevent the situation from becoming worse in the long run. Air quality protection is a key element in ensuring sustainable livelihoods for both present and future generations. Literature abounds in studies on air quality modelling and the effect of industrial emissions on ambient air quality. Below is presented a selection of works that have dealt with this topic and also the main inferences that emerge from these studies both at national and international levels.

3.1 INTERNATIONAL SCENARIO

Dispersion modelling analysis to demonstrate the air quality impacts associated with an emission trading scheme for a sintering operation in Youngstown, Ohio performed by *(Schewe et al., 1998***)**. The model demonstrated that the emission trading scheme would not result in significant air quality impacts, which lent maximum operating flexibility to the sintering facility. The study conducted by the *Toro et al., (1998)* presented the potential dispersion modelling uses of archived National Oceanic and Atmospheric Administration (NOAA) forecast model data. This newly developed generation of air quality simulation models has the potential to use wind profiles, temperature and turbulence as well as improved mixing height determination measures of surface heat flux and host of other meteorological parameters. Further a thorough technical review of the Emissions and Dispersion Modelling System (EDMS), Version 3.0.were discussed by *(Allen et al., 1998)*. The general interface design concerns, limitations on the model's use and potential errors that a user may encounter when utilizing the model as an air quality analysis tool.

Two measurement campaigns that were performed to demonstrate improvement possibilities with respect to procedures developed in the past 20 years for limiting pollution peaks around industrial sites in France's lower Seine Valley was discussed by *(Thomas et al., 1999).* Dispersion models (both Gaussian and Lagrangian) and a long path (integrating) monitor, the SANOA UV-DOAS techniques were used, in order to assess average pollutant concentrations along a line as opposed to point monitoring. A set 11 of point monitors for SO_2 and several wind sensors, including ultrasonic anemometers, and a SOund raDAR (SODAR). Mesoscale wind forecasts (the ALADIN prediction from METEO France) were also used. During the campaign, all data was collected in real time and wind model predictions were input periodically into dispersion models. Measurement and model data were analyzed after the fact to determine a better method of tailoring emission reductions to real world situations.

Dabberdt et al., (2000) addressed modelling issues related to accidental chemical releases. The application to emergency response dispersion modelling was illustrated using an actual event that involved the accidental release of the toxic chemical oleum. Both surface footprints of mass concentration and the associated probability distributions at individual receptors were seen to provide valuable quantitative indicators of the range of expected concentrations and their associated uncertainty.

The dispersion modelling system based on the combined application of an urban dispersion modelling system (UDM-FMI) and a road network dispersion model (CAR-FMI) was developed by *(Karppinen et al., 2000)* for evaluating traffic volumes, emissions from stationery and vehicular sources and atmospheric dispersion of pollution in an urban area. Similarly, *Koracin et al., (2000)* performed a comprehensive modelling study of PM_{10} impact in Treasure Valley, Idhao using ISCST3 (Industrial Source Complex Short Term model). The study reported that the input base year meteorology and gridded emissions for mobile sources, point sources and wood burning, generally agreed well with measurements in both temporal patterns and annual averages. *Meng et al., (2000)* discussed a new statistical framework for estimating carbon monoxide impacts, with the intention of replicating the microscale modelling results achieved with CAL3QHCR (CALINE3 with queuing and hot spot calculations). The results of the study showed that the proposed model can be easily and reliably used by traffic engineers to predict potential carbon monoxide exceedances at the planning stages for transportation projects. *Hassid et al., (2000)* described their experience in using US EPA Gaussian models for developing environmental impact statements that focused on four different sectors: highway, quarries, airports, and tunnels. The authors encountered several uncertainties associated with the use of dispersion models. The main problems encountered are the uncertainties in the emission factors, the lack of accounting of the complex terrain effects and the fact that the Israeli Standards relate to total NO_x concentration rather than NO.

Yegnan et al., (2001) reported the Taylor series approach for uncertainty analyses was advanced as an efficient method of producing a probabilistic output from air dispersion models. A probabilistic estimate helps in making better-informed decisions when compared to results of deterministic models. They used Industrial Source Complex Short Term (ISCST) model as an analytical model to predict pollutant transport from a point source. First- and second-order Taylor series approximations are used to calculate the uncertainty in ground level concentrations of ISCST calculations. The results of the combined ISCST and uncertainty calculations are then validated with traditional Monte Carlo (MC) simulations. The Taylor series uncertainty estimates were a function of the variance in input parameters (wind speed and temperature) and the model sensitivities to input parameters. While the input variance is spatially invariant, sensitivity is spatially variable; hence the uncertainty in modelled output varies spatially. A comparison with the MC approach showed that uncertainty estimated by first-order Taylor series is found to be appropriate for ambient temperature, while second-order Taylor series was observed to be more accurate for wind speed. Since the Taylor series approach was simple and time-efficient compared to the MC method, it provides an attractive alternative.

Air quality assessments in different scenarios were presented by *Leksmono et al., (2006)*, which were modelled using ADMS-Urban to predict concentrations of nitrogen dioxide. Investigated from a theoretical perspective, a situation where traffic was not the sole cause of an AQMA declaration .Modelling was carried out using simple scenarios with a combination of traffic and industrial emissions, different type of roads, meteorological data and approaches to derive nitrogen dioxide from oxides of nitrogen. The modelling results have shown the significance of the NO_x: NO_2 relationship and meteorological data as parameters inputted into the model. The results were discussed and compared with the guidance provided by Department for Environment, Food and Rural Affairs (Defra, UK). Similarly, *Grigoras et al., (2010)* performed the air quality assessment in a polluted area with specific and complex terrain features situated in the north-western part of Romania using the Air Pollution Model (TAPM). In order to properly assess the concentrations of air pollutants in the studied area, there were taken into account not only the emissions from the activities on the premises of the main industrial platform, but also the contribution from the other pollution sources from the area of interest, such as other industries, residential heating, traffic, dump heaps. Modelling resulted that there was significant influence of the complex terrain features and of the other pollution sources on the concentration levels in the region, usually associated with the emissions of the main industrial platform.

Sabri et al., (2011) investigated the air quality that contained pollutant gases (SO_2, NO_2, CO) released from the thermal power plant as case study in South Baghdad. Gaussian Plume Model and the computer program (visual basic 6) are used to calculate concentrations dispersion of gas pollutants at different meteorological conditions (wind speed, ambient temperature); maximum concentration values, downwind distance and required effective stack height estimation. A typical theoretical investigation of a case study concerning existing air pollution problems at an industrial area (4Km) downwind distance by using the computer program. The results showed that the concentration of SO_2 (890 $\mu g/m^3$) released from stack may is higher than the EPA standard.

TSP and PM_{10} was modelled in ISC3 and AERMOD using meteorological data by *(Jose et al., 2012).* Data was collected by 3 local stations in Northern Colombia during 2008 and 2009. High correlation coefficients (>0.73) were obtained with monitored data. Models then forecast the PM conc. and resulted in highly, fairly, moderately and marginally polluted according to local regulations leads to relocation of 3 villages.

Comparing modelled pollutant concentrations predicted by AERMOD with observed concentrations, *Schewe et al., (2003)* reported that 3- and 24-hr concentrations predicted by AERMOD were below observed levels from a refinery located in complex terrain in eastern Kentucky. However, annual concentrations predicted by AERMOD were higher than those observed**.** *Kumar et al., (2006)* also observed that model prediction was below observed concentrations but became better as the length of the averaging period increased from observations made in an urban area of Lucas County, Ohio, United States. *Ding, (2012)* applied AERMOD model to simulate the pollutant concentration at different heights in beilun district, china. The results showed that the ground daily average concentration of SO_2 was equivalent to 26.7%~53.3% of ambient air quality standard, and the concentration of NO_2 was equivalent to 16.7%~58.3%. But the concentration of SO_2 and NO_2 was relatively higher in the upper air of beilun district. The area that daily average concentration of SO_2 exceeded 200$\mu g/m^3$ is about 200 km^2, and the area that daily average concentration of NO_2 exceeded 200$\mu g/m^3$ is about 150km^2. As the SO_2 and NO_2 were acid-causing substances, there was a lot of acid substance on high altitude. It must be an important reason for the high frequency of acid rain on beilun district.

Leonor et al., (2013) evaluated the implementation of the Weather Research and Forecasting model, WRF, for its use as the meteorological pre–processor for diagnostic air quality modelling in Cuba. The results of the model were compared with the observations of the National Weather Service surface stations and showed good performance for temperature and acceptable performance for prediction of wind tendencies. The research concluded that the WRF output is able to provide realistic meteorological patterns for air quality models, which require high–resolution three–dimensional (3D) meteorological data. The WRF–fsl tool was developed to use WRF to feed the local models as AERMOD when upper air data is not available. This tool takes the WRF output and gets the upper air data, in the fsl radiosonde format. *Faulkner et al., (2008)* determined the sensitivity of AERMOD to various inputs and compare the highest downwind concentrations from a ground-level area source (GLAS) predicted by AERMOD to those predicted by ISCST3 in the San Francisco Bay area. Concentrations predicted using ISCST3 were sensitive to changes in wind speed, temperature, solar radiation (as it affects stability class), and mixing heights below 160 m. AERMOD was sensitive to changes in albedo, surface roughness, wind speed, temperature, and cloud cover. Bowen ratio did not affect the results from AERMOD. These results demonstrated the AERMOD's sensitivity to small changes in wind speed and surface roughness. When AERMOD is used to determine property line concentrations, small changes in these variables may affect the distance within which concentration limits are exceeded by several hundred meters.

3.2 NATIONAL SCENARIO

The increased air pollution levels as a result of concentrated industrial activities in Jamshedpur, the steel city of India was studied by *(Sivacoumar et al., 2001)*. The impact of NO_X emissions resulting from various air pollution sources, viz. industries, vehicles and domestic, was estimated using Industrial Source Complex Short-Term (ISCST) Gaussian dispersion model. The contribution of NO_x concentration from industrial, vehicular and domestic sources was found to be 53, 40 and 7% respectively. Further statistical analysis was carried out to evaluate the model performance by comparing measured and predicted NO_x concentrations. The model performance was found good with an accuracy of about 68%. Similarly, *Reddy et al., (2005)* had used the ISCST-3 model to study the impact of an industrial complex, located at Jeedimetla in the outskirts of Hyderabad city, India, on the ambient air quality. The emissions of SO_2 from 38 elevated point sources and 11 area sources along with the meteorological data for 2 months (April and May 2000) representing the summer season and for 1 month (January 2001) representing the winter season have been used for computing the ground level concentrations of SO_2. The 8hr. and 24hr. averaged model-predicted concentrations have been compared with corresponding observed concentrations at three receptors in April 2000 and at three receptors in May 2000 where ambient air quality is monitored during the study period. A total of 90 pairs of the predicted and observed concentrations have been used for model validation by computing different statistical errors and through Quantile–Quantile (Q–Q) plot. The results showed that the model-predicted concentrations were in good agreement with observed values and the model performance was found to be satisfactory. The spatial distribution of SO_2 concentrations over the study were within the limits in comparison to the National Ambient Air Quality Standards except near the industrial area.

The assimilative capacity and the dispersion of pollutants due to industrial sources have been studied in the Visakhapatnam bowl area situated in coastal Andhra Pradesh, India by *(Rama Krishna et al., 2004)*. Visakhapatnam hosts several major industries. The assimilative capacity of the Visakhapatnam bowl area's atmosphere has been studied using two different approaches in two seasons, namely, summer and winter of 2002–2003. The first approach was based on ventilation coefficient, which was determined through micro-meteorological data, and the second approach was based on pollution potential in terms of concentration of pollutants determined using air pollution dispersion models. The concentrations of two gaseous pollutants sulphur dioxide and oxides of nitrogen have been computed using two models, namely, Gaussian Plume Model (GPM) and Industrial Source Complex Short Term (ISCST-3) model in the Visakhapatnam bowl area in the summer and winter seasons, respectively. The concentrations of the gaseous pollutants have been measured as 8-h averages at 10 monitoring stations in summer season and at 12 monitoring stations in winter season. The computed 8-h averaged concentrations have been compared with those monitored concentrations at different receptors in both the seasons. The validation of the models has been carried out through quantile–quantile (Q–Q) plots and by computing several statistical errors. The results indicated that both models’ predictions have shown a similar trend with those observed concentrations in the study area. The GPM showed a slight over prediction whereas the ISCST-3 model showed an under prediction in comparison with the observed concentrations.

Kesarkar et al., (2006) reported the dispersion of respirable particulate matter (RSPM/PM_{10}) over Pune, India. Data from the emissions inventory development and field-monitoring campaign (13–17 April 2005) conducted under the Pune Air Quality Management Program of the MOEF. The planetary boundary layer and surface layer parameters required by AERMOD were computed using the Weather Research and Forecasting (WRF) Model (version2.1.1) developed by the National Center for Atmospheric Research (NCAR). Comparison between the simulated and observed temperature and wind fields shows that WRF is capable of generating reliable meteorological inputs for AERMOD. The comparison of observed and simulated concentrations of PM_{10} shows that the model generally underestimates the concentrations over the city.

Goyal et al., (2007) determined the atmospheric assimilation potential of a typical urban area in Kochi city, with respect to sulphur dioxide (SO_2). The ventilation coefficient is directly proportional to the assimilation potential of the atmosphere and had been computed using meteorological parameters in all four seasons (winter, summer, monsoon and post-monsoon) of the years 1998–1999 represented by January, April, July and October respectively. The diurnal variation in ventilation coefficients showed that the assimilative capacity of the atmosphere is high during the afternoon and was reduced during the evening and morning in all the seasons. Among all the seasons, monsoon and post-monsoon have the poorest assimilative capacity throughout the day. In the second approach, the assimilation potential was estimated through dispersion modelling in terms of the concentration of pollutants, which was inversely proportional to the assimilative capacity of the atmosphere. The Industrial Source Complex (ISC) dispersion model for point sources had been used to predict the spatial and temporal distribution of SO_2 under three different industrial scenarios (type of industries existing in the Kochi region, refinery and power plant). The model predictions indicate that monsoon was the most critical season having maximum pollution, followed by summer and post-monsoon. Lowest pollution was observed in winter. The assimilative capacity in terms of the ventilation coefficient was very poor indicating high pollution potential in all the seasons. However, dispersion modelling suggests that if industrial development was planned properly, additional industrial sources can be accommodated by restricting the emission loads to be within the assimilation potential of the region.

Bhati et al., (2009) estimated that the transportation Sector had the greatest contribution (~66.4 %) towards total PM concentration followed by domestic waste (~30.8 %) and power plants (~2.7%) estimated using AERMODE. Mortality assessment revealed that 20% decrease in vehicular emissions leads to five times greater reduction in mortality count as compared to a major shift from coal to natural gas sources in power production sector. Similar studies were done at Patnagar for source contribution of ambient NO_2 concentration using models (GFLSM) and (ISCST-3) by *(Banerjee et al., 2011).* Models simulation indicated that contribution of NO_2 from industrial and vehicular source was in a range of 45–70% and 9–39% respectively. Further, statistical analysis revealed satisfactory model performance with an aggregate.

Kansal et al., (2011) study investigated that how the ambient air quality of Delhi would improve if the World Bank emission guidelines (WBEG) for the thermal power plants (TPPs) were to be implemented. . To accomplish this, a comprehensive inventory of point, area, and line sources was conducted in the selected study area, primarily aiming to estimate the sectoral emission contributions to ambient air quality. The (ISCST3) Version 3 was used to predict the ambient concentrations of total suspended particulates (TSP), sulphur dioxide (SO_2), and nitrogen dioxide (NO_2) at seven monitoring sites (receptor locations) operated by the Central Pollution Control Board (CPCB) for the period from July 2004 to June 2005. The ISCST3 model predictions for TSP and NO_2 were satisfactory at all receptor locations but for SO_2 only at two receptor locations. The vehicles and TPPs contributing 58% and 30% respectively. The study estimated that adoption of WBEG may reduce the ambient air pollution due to TPPs emissions by 56% to 82%, bringing it within the National Ambient Air Quality Standards (NAAQS) set for industrial areas in India, except at one location where TPP’s contribution to ambient air pollution is negligible compared to vehicular emissions. *Namdeo et al., (2012)* reported on the applicability and performance of some well known air quality dispersion models like AERMOD and ISCST3 models for Indian conditions. The evaluation of these models has been carried out in Delhi, India using the historical air quality, meteorological and traffic data for the year 2007. The models have been evaluated using standard performance indicators like fractional bias, mean bias, normalized root mean square error and index of agreement and. Model performance was in generally adequate for NO_2 and CO, but not for $PM_{2.5.}$ It is advised that air quality modellers in India acquire data that is representative of the study domain before informing policy makers of their findings.

3.3 Research gaps

Few reports highlight the air quality of critically polluted industrial areas in India but still study is incomplete and partial in comparison to global scenario. Further, no detailed study of the prediction of ground level concentrations at sensitive receptors using dispersion modelling has been published in industrial estate (Mandi Gobindgarh). Air quality in urban areas can be determined either by monitoring or by prediction models. Monitoring provides data on actual existing condition, but practically and economically it is not possible to monitor at every location of interest to get spatial and temporal mapping. Also it does not support prediction of future state. Further emission inventories were reported for rare areas leads to difficulty in compiling the input data for modelling.

3.4 Objectives of the present study

- Prediction of ground level concentrations at sensitive receptors using air dispersion modelling technique (AERMOD Model).
- Validation of the model with the existing air quality at the study area.

CHAPTER 4

MATERIALS AND METHODS

In this chapter, materials and methods used in this study are described in details, including chemicals, instruments, computational technique (AERMOD) and procedures used for stacks sampling and analysis of pollutant concentrations at different receptor points.

4.1 Chemicals used

The different chemicals used in the experiments are listed as

- Barium chloride solution
- Sodium Hydroxide
- Sodium Arsenite
- Absorbing solution: Dissolve 4 g of sodium hydroxide in distilled water and make up the volume to 1000 ml.
- Sulphanilamide Solution: Dissolve 20 g of sulphanilamide in 700 ml of distilled water. Add 50 ml of 85% phosphoric acid, mix and make the volume to 1000 ml. This solution is stable for one month, if refrigerated.
- N-(1-Naphthyl)-ethylenediamine Di-hydrochloride (NEDA) Solution: Dissolve 0.5 g of NEDA in 500 ml of distilled water. This solution is stable for one month, if refrigerated and protected from light. (1% aqueous solution should have only one absorption peak at 320 nm over the range of 260-400 nm. NEDA showing more than one absorption peak over this range is impure and should not be used.)
- Hydrogen Peroxide Solution: Dilute 0.2 ml of 30% hydrogen peroxide to 250 ml with distilled water. This solution may be used for one month, if, refrigerated and protected from light.
- Phosphoric Acid: 85%
- Sodium nitrite: Assay of 97% $NaNO_2$ or greater.
- Sodium nitrite stock solution (1000 μg NO_2/ml) Dissolve desiccated $NaNO_2$ 1.5g (assay 100%) or 1.5/assay % (for assay less than 100%) in 1000 ml of distilled water.
- Sodium nitrite solution (10 μg NO_2/ml.)
- Sodium nitrite working solution (1 μg NO_2/ml) (Dilute with absorbing reagent, prepare fresh daily) .

4.2 Instruments used

4.2.1 High Volume Sampler with gaseous attachment

High Volume Samplers are the basic instruments used to monitor ambient air quality. In this study, Envirotech APM 415 with its attachment for gaseous pollutant monitoring APM 411 was used. In these samplers, air-borne suspended particulates (SPM) are measured by passing air at a high flow-rate of 1.1 to 1.7 cubic meters per minute through a high efficiency filter paper (Whatman 934-AH Glass Microfiber Filters) which retains the particles. The instrument measures the volume of air sampled, while the amount of particulates collected is determined by measuring the change in weight of the filter paper as a consequence of the sampling. In High Volume Sampler provisions have been made for simultaneous sampling of gaseous pollutants. Gaseous attachment contains three impinger bottles of 35 ml capacity for simultaneous absorption of different gaseous pollutants. Here the air is passed through suitable reagents that would absorb specific gases where gaseous pollutants like SO_2, NO_2 etc. are analyzed subsequently by simple wet chemistry method to determine the concentration of specific pollutant. The gaseous sampling requires only a few LPM (1-3 LPM) of air flow. This absorbing solution is placed within the impinger bottles placed in between ice cubes or cold water, for complete absorption of sparsely soluble gases. These absorbing solutions can then be taken directly to the laboratory for analysis.

Fig 4.1: High Volume Sampler APM 415

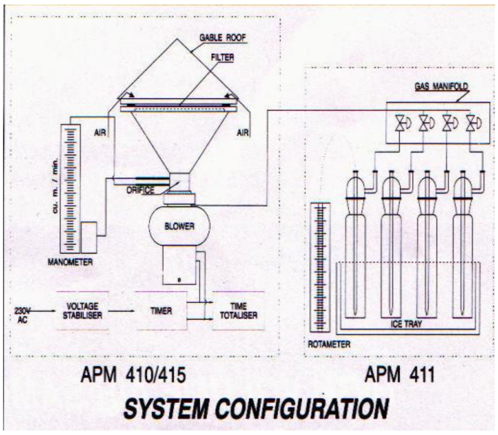


Fig 4.2: System Configuration of gaseous extension with HVS

4.2.2 Weather Monitoring Station (WMS)

The weather monitoring station used in this study was Watch Dog of Spectrum Series 2000. The Watch Dog weather station is a multifunction device which allows to detect as well as store seven parameters including wind speed, wind direction, temperature, relative humidity, dew point, pressure and solar radiations using different sensor for each. The Watch Dog weather station is used in agriculture and gardening as well as in industry, and in the research sector. Its measurement ranges are wind speed: 0 to 281 Km/hr; wind direction: 0 to 360°; air temperature: -20 to +70°; air humidity: 20 to 100% and rainfall: 6.5cm measurement period.

Weather monitoring station must be installed at site where there is no obstruction in path of wind so that correct data can be collected. It consist of lightweight three cup type anemometer for measuring wind speed ranging from 0 to 150 mph and wind vane for the determination of wind direction. Interval for the data collection can be chosen between 1 to 60 minutes. Data logger allows storage of data for 6 months at a time and the stored data can be transferred to computer using data cable.

Figure 4.3: Weather monitoring station

4.2.3 Flue Gas Analyzer

For stack monitoring, flue gas analyzer used in the study was Testo 340 Flue gas analyzer. Testo 340 is a single solution for a range of applications from stack monitoring, to burner tuning, optimizing combustion process in boilers and furnaces, from diesel engine exhausts analysis, to NO_X monitoring gas turbines, from flue gas analysis in incinerators, to measuring emissions in gas engines. Testo 340 flue gas analyzer includes a rechargeable battery, self calibration protocol, and sampling probe of varying lengths of 12 inch to 28 inch can withstand temperature upto 1800°C. The standard probe hoses are heat resistant extend to 25feet with extension. It is equipped with O_2 sensor and we can add upto three additional sensors for CO(0-10,000ppm), NO(0-3,000ppm), NO_2(0-500ppm) or SO_2(0-5,000ppm) as per requirement and built-in flow/differential pressure measurement. There are 18 standard fuels options available in this along with option for 10 additional user defined fuels. For data transfer there is a option of USB or it can directly be attached to printer.

Figure 4.4: Flue Gas Analyzer with probes

4.3 Dispersion Modelling Technique (AERMOD)

Atmospheric dispersion modelling is the mathematical simulation of how air pollutants disperse in the ambient atmosphere. It is performed with computer programs that solve the mathematical equations and algorithms which simulate the pollutant dispersion. It is useful to determine whether emissions of existing or proposed new industrial facilities are or will be in compliance with the National Ambient Air Quality Standards (NAAQS), to check the effective control strategies to reduce emissions of harmful air pollutants and used by public safety responders and emergency management personnel for emergency planning of accidental chemical releases and also to determine the consequences of accidental releases of hazardous or toxic materials. Air quality modelling software named AERMOD (Version

8.0.5) was used to predict the ground level concentration (include isopleths showing areas of minimal to high concentrations) of various pollutants from major point sources.

Model overview

AERMOD is a straight-line, steady-state plume model that is an improvement over ISC-PRIME in that it incorporates recent boundary layer theory and advanced methods for handling terrain. AERMOD contains improved algorithms for: dispersion under stable and unstable conditions; plume rise and buoyancy; plume penetration into elevated inversions; treatment of elevated, near-surface, and surface level sources; computation of vertical profiles of wind, turbulence, temperature and terrain effects on plume behaviour. AERMOD also includes the PRIME building downwash algorithms. Model improvements and features are discussed in detail in (*Cimorelli et al., 1996).*

AERMOD is actually a modelling system with three separate components: AERMOD (AERMIC Dispersion Model), AERMAP (AERMOD Terrain Pre-processor), and AERMET (AERMOD Meteorological Pre-processor). The flow and processing of information in AERMOD has been presented in Figure 4.4. The major purpose of AERMET is to calculate boundary layer parameters. The meteorological INTERFACE, internal to AERMOD, uses these parameters to generate profiles of the needed meteorological variables. AERMAP purpose is to provide a physical relationship between terrain features and the behaviour of air pollution plumes.

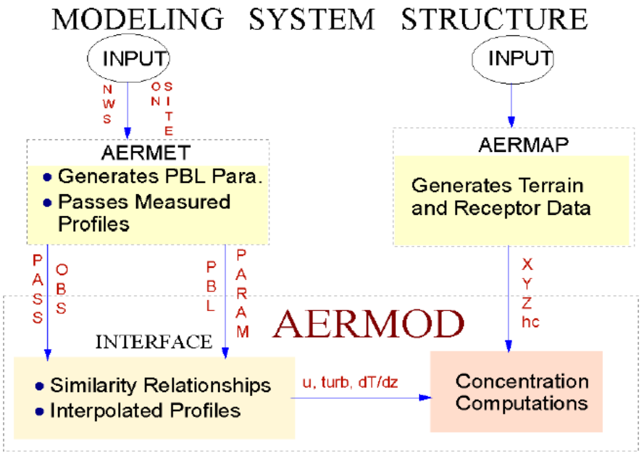


Figure 4.5: Data flow in the AERMOD modelling system

4.4 Methodology

The study was carried out in three steps which are:

- Selection of sampling site
- Meteorological and source emission monitoring
- Use of AERMOD for modelling

4.4.1 Selection of sampling site

The study area Mandi Gobindgarh stands the 17th most polluted industrial town in India and is one among the list of critically polluted industrial hubs of the country. In Mandi Gobindgarh town, out of total area of 9 sq. km. (2223acs.) 33.74% is occupied by industries. The CEPI score for Mandi Gobindgarh has been observed to be 75.08.. The Punjab Pollution Control Board has identified 6 industrial clusters within the jurisdiction of Mandi Gobindgarh, out of which, Focal point was chosen to prepare source inventory as it includes mainly rolling mills, induction furnaces, refractories etc., so sampling is done in some of the representative industries so that all types of industries get covered. In first step, 26 sampling sites were selected on the basis of major stacks in industrial area and types of industries. Figure 4.6 (a) shows the study area, the 26 major stacks are identified (with the help of ground truth surveys and data provided by the PBCB, Mandi Gobindgarh). With the help of Google earth the study area were identified along with major sensitive receptor areas (Ajnali residential area-A, Ambe majra residential-B, RIMT college-C, PPCB-D, Chattarpur zoo-E, floating restraint-F) shown in figure 4.6(b). Red colours marks in the figure 4.6(b) indicate the representative sampling stacks and green marks indicates the sensitive receptors.

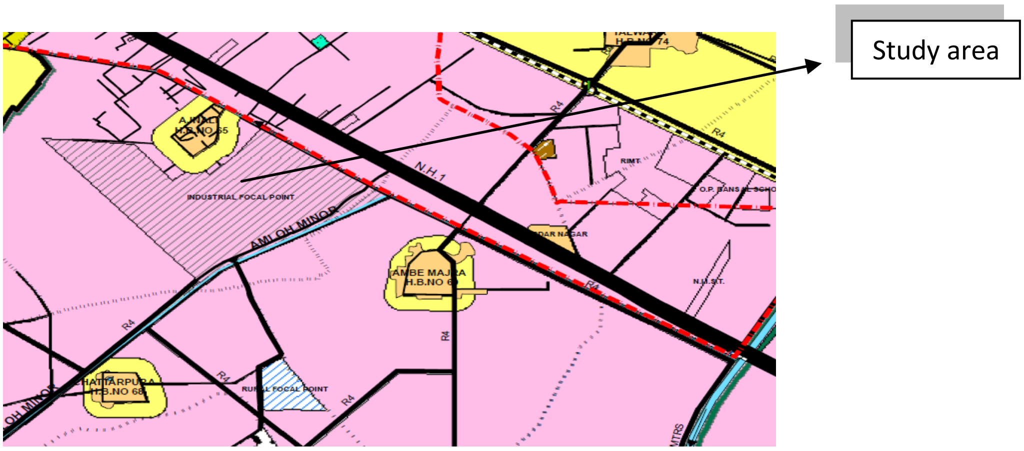


Figure: 4.6(a) Represents the study area

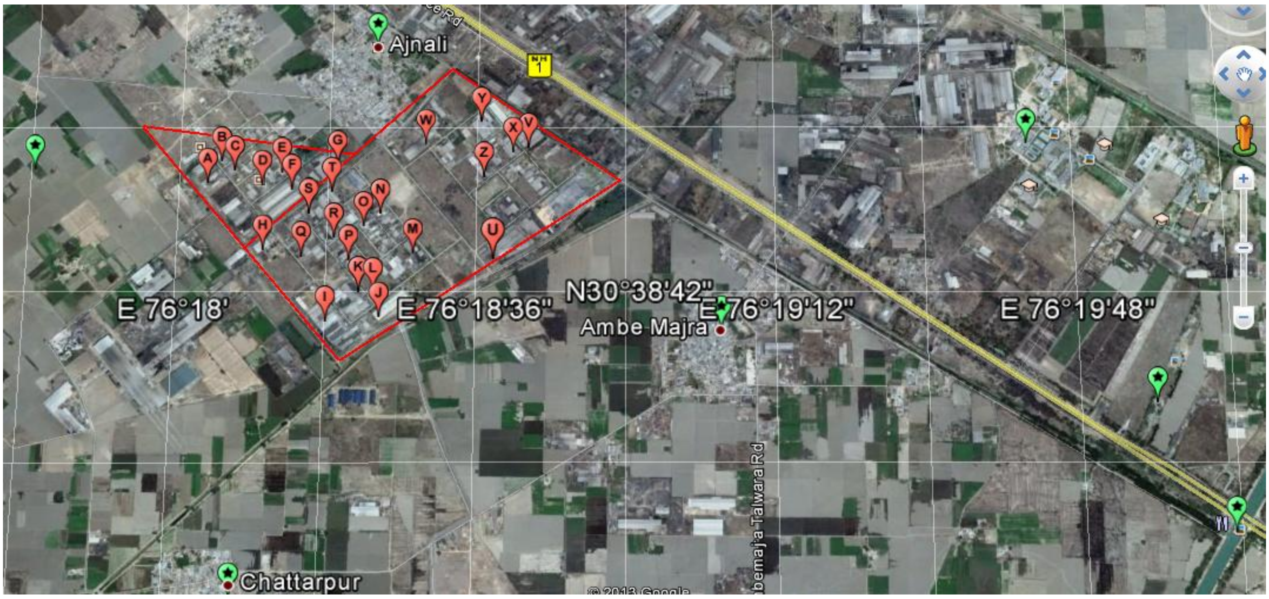


Figure 4.6(b): Study area with sampling sites and receptors

4.4.2 Meteorological Monitoring

The meteorological factors affect a range of atmospheric characteristics and dispersal of pollutants. These factors and their frequent changes control the gravity and intensity of air pollution in an area and cause seasonal variations in horizontal as well as vertical distribution and fate of respective pollutants. The essential meteorological parameters required for modelling are wind speed, wind direction, ambient air temperature, relative humidity, rainfall, atmospheric pressure, cloud cover, ceiling height and solar radiation. Meteorological data was collected for daily mean hourly data through-out the study period of one year i.e. May 2012 to April 2013 to ensure proper representation of the activities. Weather Monitoring Station was installed at DBTES, Thapar University (30°35'39"N, 76°37'07"E), Patiala. Additional meteorological data for the study period was collected form Indian Meteorological Department (IMD) Station ID-42101, Patiala. The meteorological data was valid to nearby 30 Km areas. Meteorological data then compiled in an excel file for further processing by AERMET.

4.4.3 Source Emission Monitoring

The dispersion of pollutants along with meteorological conditions also depends upon the source characteristics (emission rate, exit velocity of gases, exit temperature of gases, stack height and stack diameter) includes in the emission inventory. The type of industry along with its production capacity, type of fuel used, peak working hour of the industry and other relevant data was collected from the Punjab Pollution Control Board (PBCB), Mandi Gobindgarh. For 26 sampling sites stack height and stack diameter data was collected from the respective industries during monitoring.

Period, frequency and duration of stack monitoring

Stack monitoring measurement campaign was carried out at periodic intervals, such as once every three months at the peak working hour of the industry and the frequency of stack sampling was done according to CPCB guidelines *(Emission regulations, CPCB (1985)* for the SO_2 and NO_2 concentrations. The sampling site was selected such that a laminar flow of air is present in the stack. In case of rectangular stacks, the larger dimension will be used to represent the stack diameter. The minimum required number of traverse points is a direct function of stack or duct diameter shown in Table 4.1 so traverse points number chosen during sampling varies industry to industry.

Table 4.1: Minimum required number of traverse points for sampling sites which meet specified criteria.

Inside diameter of stack or duct (m)	Number of points
I.D ≤ 0.3	4
0.3 ≤ I.D ≤ 0.6	8
0.6 ≤ I.D ≤ 1.2	12
1.2 ≤ I.D ≤ 2.4	20
2.4 ≤ I.D ≤ 5	32

Sampling duration was kept at 20 minutes and isokinetic samples were collected. Flue gas analyzer, an automatic device was used for sampling. Calibration of the Flue gas analyzer was done before each sampling. The average emissions from representative stacks were taken to compile the emission inventory further used by AERMOD.

4.4.4 Use of AERMOD

In order to conduct a refined air dispersion modelling project using the U.S. EPA AERMOD short term air quality dispersion model, the meteorological data of the area need to be processed being modelled using the U.S EPA AERMET program.

AERMET processes meteorological data in three stages:

1. Stage 1- Extraction and Quality Assessment: in this stage, the data is extracted/ retrieved and the assessment of the quality of the data is performed.
2. Stage 2- Merging Data: in this stage, the files from stage 1 are combined into a single ASCII file.
3. Stage 3- Creating AERMOD Model Input Files: in this stage, the merged file is read in conjunction with site-specific parameters and two files are produced for input to

AERMOD. The first file, Surface file (*.sfc), contains boundary layer scaling parameters and reference-heights winds and temperature. The second file, Profile file (*.pfl), contains one or more levels (profile) of winds, temperature and the standard deviation of the fluctuating components of the winds. Wind roses were also plotted.

AERMAP (terrain data pre-processor) was not required as study area was a flat terrain.

AERMOD run stream setup file contains five control pathways representing the selected modelling options, as well as source location, receptor locations, meteorological data file, and output options. AERMOD requires two types of meteorological data files that are provided by AERMET. One file consists of surface scalar parameters, and the other file consists of vertical profiles of meteorological data.

AERMOD has five pathways

CO- Control pathway: It specifies the overall job control options such as dispersion options, pollutants and averaging times.

SO- Source pathway: It specifies the source input parameters and source group information such as source types, building downwash and variable emissions

RE- Receptor pathway: It specifies the receptor locations for a particular run, defining the number and types of receptor and receptor groups.

ME- Meteorology pathway: It specifies the meteorological data file and information about the meteorological stations.

OU- Output pathway: It specifies the output options for particular run such as contour plots files.

4.5 Validation of AERMOD model

Accuracy of the model prediction depends upon accuracy of the input data used. The data collected always might not be accurate and this deviate model results from actual measured concentrations. Also, there are some uncertainties associated with model itself. A model predicts concentrations averaged over a certain volume, whereas measurements are made at a point. So to gain confidence about the predicted results of the model, it had been validated.

AERMOD was validated for SO_2 and NO_2 concentration using air quality monitoring data at RIMT College receptor site and NMSE (Normalised Mean Square Error) were calculated. Smaller the error denotes better model performance and makes results feasible for further uses. Air monitoring was carried out at periodic intervals, such as once every three months for 24hr duration using HVS (high volume sampler) along with impinger train.

SO_2 analysis

SO_2 is gravimetrically estimated by adding barium chloride in slight excess in absorbing solution. H_2O_2 is used as an absorbing solution which gets converted to sulphuric acid during sampling (Eq. (1)).

$H_2O_2 + SO_2 \rightarrow H_2SO_4$ ………………………………………………………….. (1)

$H_2SO_4 + BaCl_2 \rightarrow BaSO_4 + 2HCl$ ………………….………………………………(2)

When barium chloride reacts with sulphuric acid (Eq. (2)), it leads to the formation of barium sulphate which is estimated gravimetrically. With stoichiometric calculation, we estimate sulphur dioxide concentration in ambient air. Steps followed for SO_2 analysis:

- Install high volume sampler with its gaseous extension having impinger bottles filled with 30 ml of absorbing solution. Set flow rate of air flow in between 0.2 to 1 LPM.
- After sampling for 24 hrs, add $BaCl_2$ in excess to absorbing solution while slightly heating, as to precipitate SO_4^{2-} as $BaSO_4$.
- Once the reaction is completed, the precipitates formed are filtered on a pre-conditioned and pre-weighed Whattman filter paper. After filtration, the precipitates are dried in an oven and final weight of filter paper is recorded.
- Difference of the final weight and initial weight of the filter paper gives the amount of precipitates formed. With the help of stoichiometric calculations, calculate the concentration of SO_2 in the ambient atmosphere.

  SO_2 concentration can be calculated by

$$\mathbf{SO_2 = (Mol.\ wt.\ of\ SO_2 * W * 10^6)/(\ Mol.\ wt\ of\ BaSO_4 * Va)}$$

Where, SO_2= Concentration of SO_2, ug/$m^{3;}$ V_a= Total air volume sampled, m^3; W= weight of $BaSO_4$ formed i.e. difference between filter paper before and after filtration, (g).

NO_2 analysis

Ambient nitrogen dioxide (NO_2) is collected by bubbling air through a solution of sodium hydroxide. The concentration of nitrite ion (NO_2) produced during sampling is determined colorimetrically by reacting the nitrite ion with phosphoric acid, sulfanilamide, and N-(1-

naphthyl)-ethylenediamine di-hydrochloride (NEDA) and measuring the absorbance of the highly coloured azo-dye at 540 nm. Steps taken during NO_2 sampling are as follows:

Preparation of Standards

1. Pipette 2, 4, 5, 6 ml of working standard solution in to 50 ml volumetric flask and fill to 20 ml mark with absorbing solution.
2. A reagent blank with 10 ml absorbing solution is also prepared.
3. Pipette in 1 ml of hydrogen peroxide solution, 10 ml of sulphanilamide solution and 1.4 ml of NEDA solution, with thorough mixing after the addition of each reagent and make up to 50 ml with distilled water.
4. Read the absorbance of each standard and reagent blank against distilled water reference after 10 minute color development interval.
5. Standard curve is plotted having absorbance on Y axis versus concentration at X axis.

Sample Analysis

1. Prepare absorbing reagent (a solution of sodium hydroxide and arsenite) by dissolving 4g of sodium hydroxide and 1g of sodium arsenite in 1lit of distilled water. A drop of H_2O_2 is added to remove interference of SO_2.
2. Place 30 ml of absorbing solution in an impinger bottle and are sampled for 24 hrs using HVS at the flow rate of 0.2 to 1 L/min.
3. After sampling measure the volume of sample and transfer to a sample storage bottle.
4. Replace any water lost by evaporation during sampling by adding distilled water up to the calibration mark on the absorber, mix thoroughly.
5. Pipette out 10 ml of the collected sample into a 50 ml volumetric flask.
6. Pipette in 1 ml of hydrogen peroxide solution, 10 ml of sulphanilamide solution and 1.4 ml of NEDA solution, with thorough mixing after the addition of each reagent and make up to 50 ml with distilled water.
7. Prepare a blank in the same manner using 10 ml of unexposed absorbing reagent.
8. After a 10 min colour development interval, measure and record the absorbance of samples and reagent blank at 540 nm using distilled water as the optical reference.

Values of NO_2 concentration can be taken from the standard curve plotted between concentration and absorbance and then divided by the volume of air sampled.

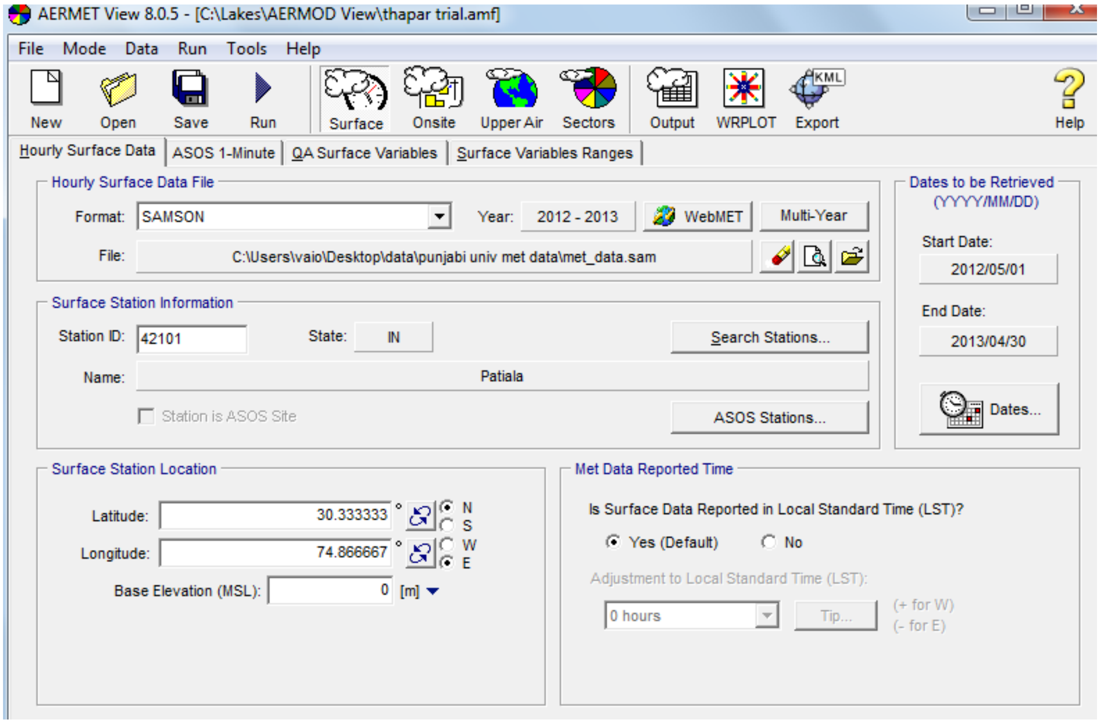
CHAPTER 5

RESULTS AND DISCUSSION

This chapter deals with the input data such as meteorological source and land use to generate wind roses and the isopleths for estimating concentrations of SO_2 and NO_2 at different receptor points. As discussed in methodology, the study area was earmarked with twenty six sampling sites and six sensitive receptors locations were chosen as shown in Figure 4.5(b) for air dispersion modelling. Meteorological and source emission inventory was prepared to be used in AERMOD software which was employed for modelling.

5.1 AERMET

Mean hourly meteorological data for one year period May 2012 to April 2013 was collected from Weather Monitoring Station (DBTES, Thapar University, Patiala) and IMD, Station ID-42101, Patiala. This surface data was imported to AERMET View 8.0.5 (Figure 5.1). The excel file was further converted to Samson format (.sam) required to run AERMET.



Format: SAMSON

Year: 2012 - 2013

File: C:\Users\vaio\Desktop\data\punjabi univ met data\met_data.sam

Station ID: 42101

State: IN

Name: Patiala

☐ Station is ASOS Site

Start Date: 2012/05/01

End Date: 2013/04/30

Latitude: 30.333333 ° ● N ○ S

Longitude: 74.866667 ° ○ W ● E

Base Elevation (MSL): 0 [m]

Is Surface Data Reported in Local Standard Time (LST)?

● Yes (Default) ○ No

Adjustment to Local Standard Time (LST): 0 hours

Figure 5.1: Screen shot for the main input window of AERMET View 8.0.5

The meteorological parameters included were wind speed, wind direction, ambient air temperature, relative humidity, rainfall, atmospheric pressure, cloud cover, ceiling height and solar radiation. Along with surface data, upper air and surface characteristics were also imported. For upper air data, the software has an option of upper air estimator that estimates upper air data from hourly surface data. Surface parameters (Albedo – 0.2075, Bowen ratio-1.625 and surface roughness- 1) values were selected as per urban land use of the study area. AERMET processes all input data in three stages and generated two output files (surface file and profile file) and wind rose plots (Figure 5.2). Surface file (.sfc) estimates boundary layer parameters and profile file (.pfl) estimates multiple level observations of wind speed, wind direction, temperature and standard deviation of the fluctuating wind components. These files were further used as such for AERMOD.

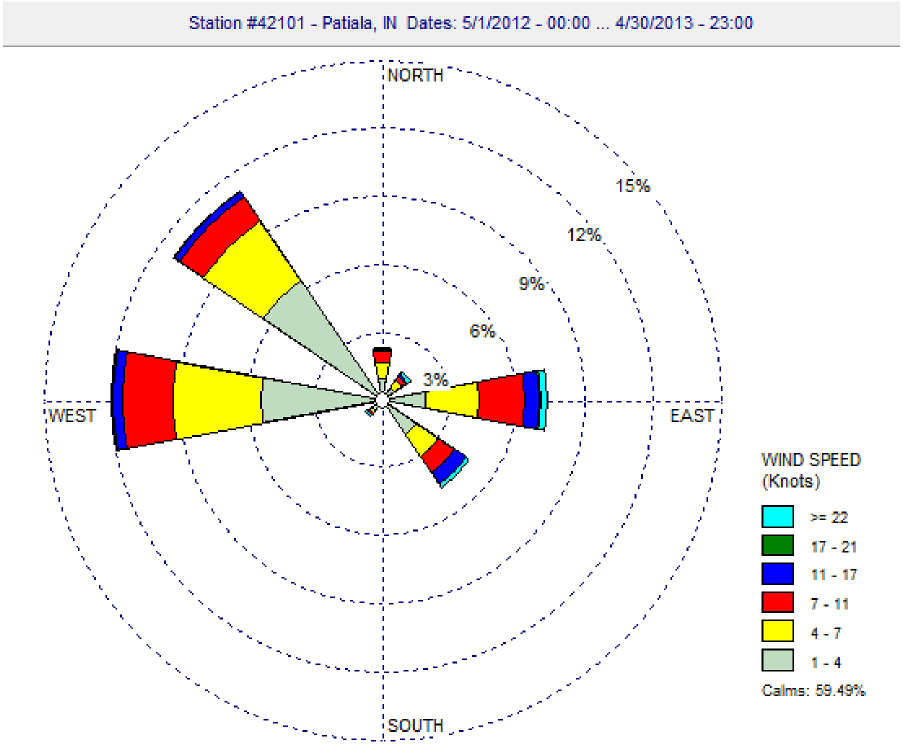


Figure 5.2: Wind rose diagram

Wind rose depicts that the pre-dominant wind direction was from West with 59.87 % frequency of calm winds and the wind speed was 2.95 Knots (1 Knot = 0.5144m/sec.). Hence, this pictorial view showed the dispersion of pollutants was towards East-South side, the downwind distance upto which wind can cause pollutants to travel was further estimated with AERMOD along with pollutants concentrations. Sensitive areas towards East-South directions (i.e. Ambe Majra residential area, RIMT College and Chattarpur Zoo and Floating restraunt) were taken as receptors to estimate the concentrations of the pollutants.

5.2 AERMOD

In order to conduct an air dispersion modelling project using the U.S. EPA AERMOD, first of all base map of the study area was imported with the help of Google earth as shown in Figure 5.3. With the help of UTM co-ordinates sampling sites and receptors were located.

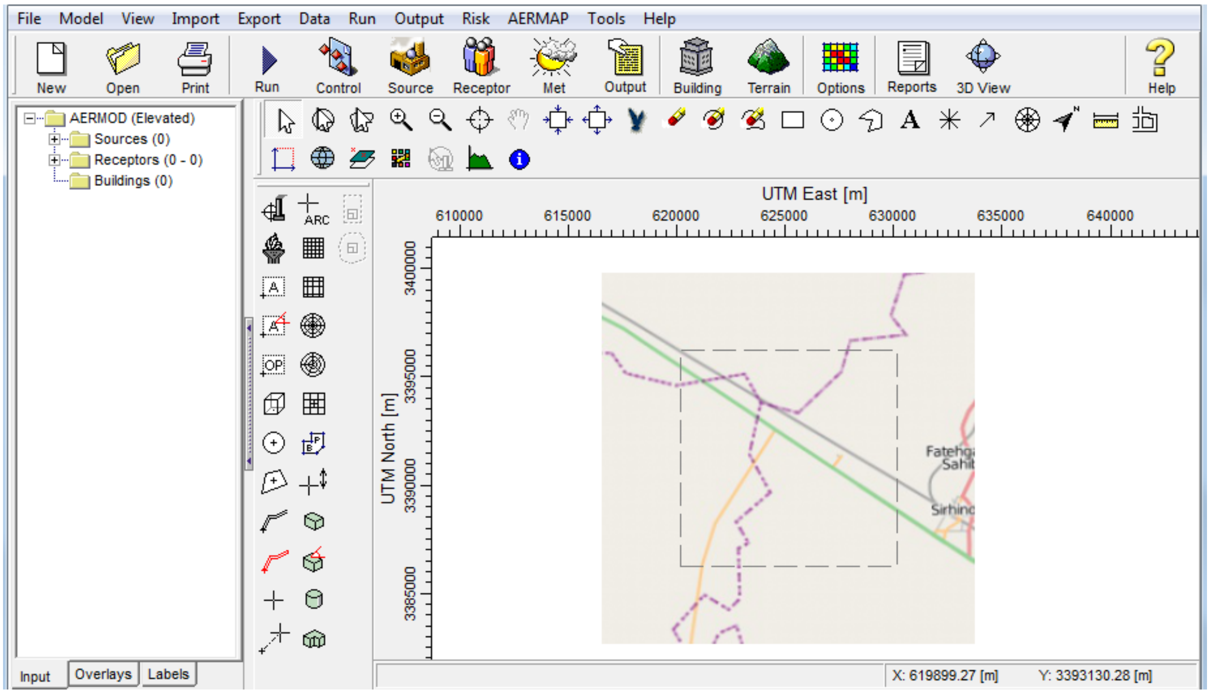
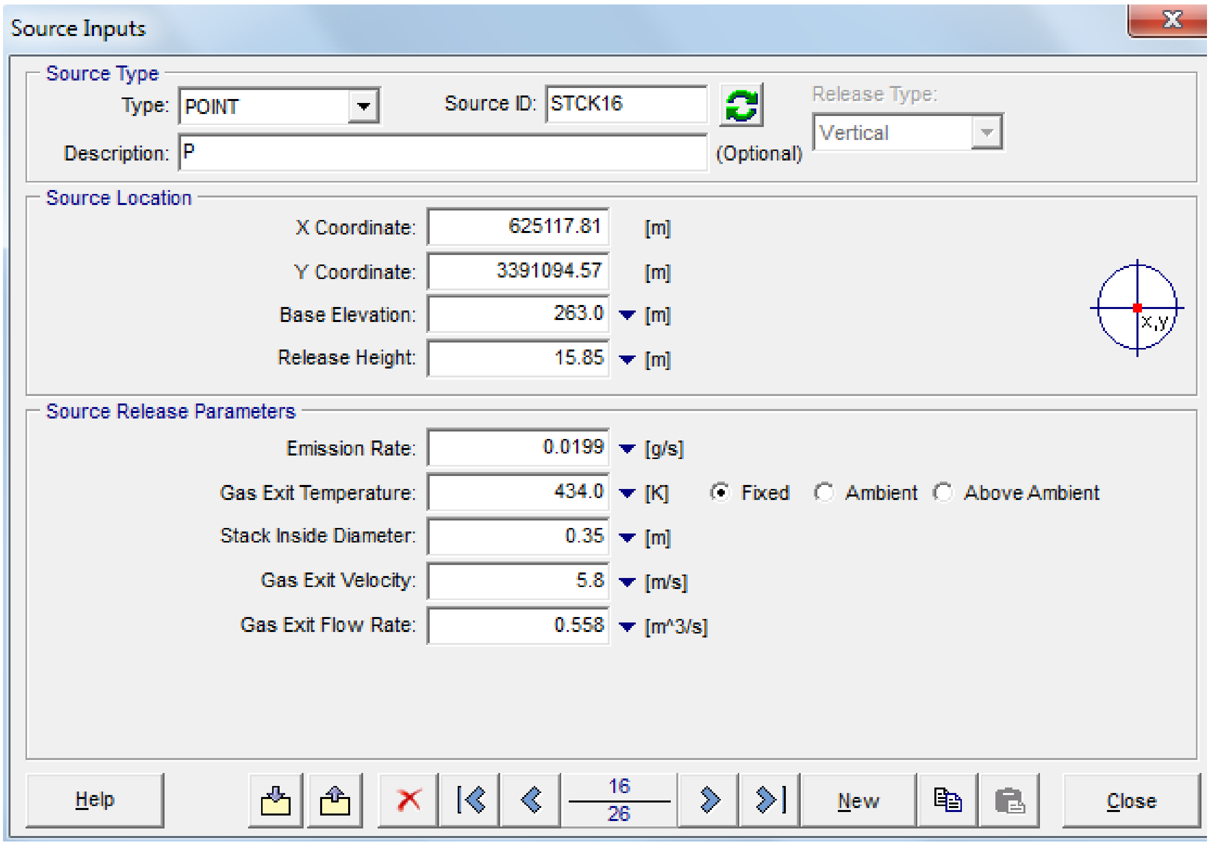


Figure 5.3: Screenshot of AERMOD main window having base map of study area

As shown in Figure 5.3, there are five mandatory pathways (Control, Source, Receptor, Meteorological and Output) and rest the use of two (Building and Terrian) pathways depends upon the conditions of study area. The study area (Focal point , Mandi Gobindgarh) is a flat terrain area and no building downwash was considered in this study. First of all, in **Control pathway** the type of pollutant (SO_2 and NO_2) and averaging time values for output concentrations of 3hr, 24hr and periodically was selected with rural dispersion coefficient. After that in **Source pathway** the type of pollutant and the source characteristics (emission rate, exit velocity of gases, exit temperature of gases, stack height and stack diameter) data were added as shown in Figure5.4. The emission inventory was prepared for the twenty six representative industries. The data was collected from stack monitoring measurement campaign carried out at periodic intervals (once every three months for one year at the peak working hour of industry). The average emissions from representative stacks were taken to compile the emission inventory as shown in Table 5.1.

Table 5.1: Estimated average emissions from representative stacks in industrial areas

Source name	**Ht. of stack (m)**	**Temp (K)**	**Stack exit velocity (m/s)**	**Stack dia. (m)**	**Flow rate (m^3/sec)**	**NO_2 ppb**	**NO_2 (g/s)**	**SO_2 Ppb**	**SO_2 (g/s)**
STACK-A	30.4	333	5.5	0.3	0.388	25000	0.01824	22000	0.02236
STACK-B	20	363	7.24	0.35	0.696	36000	0.0471	37000	0.0674
STACK-C	36.57	412	5.63	0.91	3.66	18000	0.1238	11000	0.10548
STACK-D	9.72	408	11.11	0.4	1.39	21000	0.05487	24000	0.08740
STACK-E	12.16	434	8	0.3	0.56	36000	0.0379	49000	0.0757
STACK-F	35	351	5.52	0.37	0.593	28000	0.0312	37000	0.05748
STACK-G	12.16	424	8	0.3	0.565	20000	0.0212	28000	0.0414
STACK-H	30.4	369	6.7	0.4	0.841	19000	0.0300	34000	0.0749
STACK-I	22	370	6.8	0.15	0.120	23000	0.00518	21000	0.00660
STACK-J	36.57	412	5.63	0.91	3.66	12000	0.08256	20000	0.19178
STACK-K	24.32	472	7.8	0.15	0.137	46000	0.01184	77000	0.02763
STACK-L	24.38	413	6.5	0.30	0.459	28000	0.02416	19000	0.02284
STACK-M	19.81	383	6.63	0.4	0.833	28000	0.04384	17000	0.03710
STACK-N	24.32	363	6.41	0.3	0.453	33000	0.02810	23000	0.02729
STACK-O	21.28	331	5.18	0.6	1.464	27000	0.0743	28000	0.06520
STACK-P	15.85	434	5.8	0.35	0.558	21000	0.0220	28000	0.040
STACK-Q	25.84	341	6.4	0.32	0.514	21000	0.02029	22000	0.0296
STACK-R	22	343	4.3	0.32	0.345	42000	0.02724	33000	0.02982
STACK-S	35	395	5.8	0.25	0.284	18000	0.00961	20000	0.01488
STACK-T	21.28	371	7.51	0.3	0.530	46000	0.04583	33000	0.04582
STACK-U	30	381	10.5	0.6	2.96	17000	0.09460	23000	0.17836
STACK-V	21.28	378	6.7	0.25	0.328	28000	0.01726	18000	0.01546
STACK-W	12.16	305	5.29	0.3	0.374	28000	0.01968	24000	0.02351
STACK-X	13.68	423	7.03	0.45	1.118	21000	0.04413	29000	0.08494
STACK-Y	21.28	378	6.7	0.25	0.329	46000	0.02845	38000	0.03275
STACK-Z	12.16	424	8	0.45	1.272	24000	0.05730	27000	0.08998



Type: POINT

Source ID: STCK16

Release Type: Vertical

Description: P (Optional)

X Coordinate: 625117.81 [m]

Y Coordinate: 3391094.57 [m]

Base Elevation: 263.0 [m]

Release Height: 15.85 [m]

Emission Rate: 0.0199 [g/s]

Gas Exit Temperature: 434.0 [K] ● Fixed ○ Ambient ○ Above Ambient

Stack Inside Diameter: 0.35 [m]

Gas Exit Velocity: 5.8 [m/s]

Gas Exit Flow Rate: 0.558 [m^3/s]

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Figure 5.4: Source input screenshot of AERMOD

In **Receptor pathway**, Uniform Cartesian grid and 6 discrete Cartesian receptors were located in base map to get the pollutant concentrations on the sensitive sites of the study area.

In **Meteorological pathway,** the output files of AERMET surface and profile files (.sfc and .pfl) were taken directly as meteorological input from Aermet.

In **Output Pathway** the contour plot (isopleths) files were selected to get the output, they show the area of minimal to high concentrations. Averaging time was selected as 1 h, 24 h and periodic averages for NO_2 and SO_2 concentrations. With the above specified conditions, AERMOD was run for flat terrain for SO_2 and NO_2 pollutants. Model outputs were depicted as isopleths given in Figures 5.5, 5.6 and 5.7 for NO_2 and Figures 5.8, 5.9 and 5.10 for SO_2 respectively.

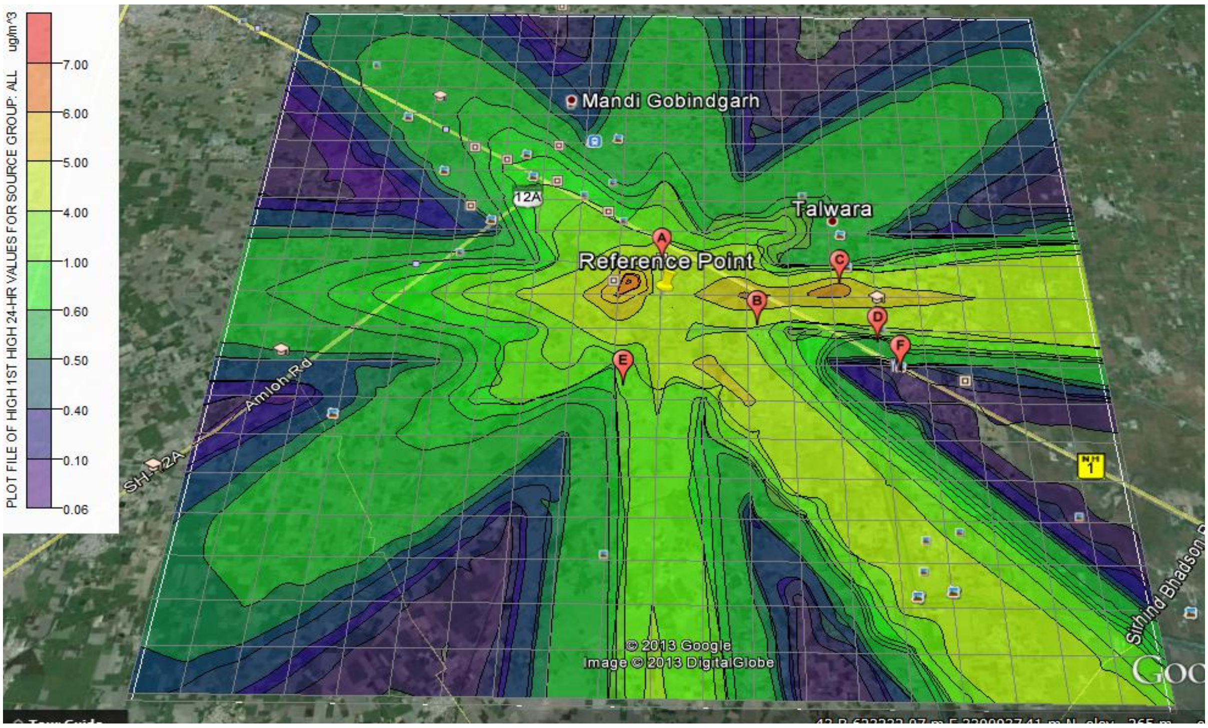

Figure 5.5: Isopleths showing dispersion of NO_2 for 1h averaging time

Figure 5.6: Isopleths showing dispersion of NO_2 for 24h averaging time

Figure 5.5 depicts the isopleths for 1h NO_2 concentrations in the entire study area. It covers - for six major receptors, viz., A (Ajnali residential area), B (Ambe Majra residential area), C RIMT College), D (PPCB), E (Chattarpur Zoo) and F (Floating restaurant, picnic spot). The model output predicted higher concentration at receptor C (11.87µg/m^3) which is a education institute area, followed by B and A receptors having concentration of 6.43µg/m^3, which are residential areas and then at receptor E with 4.3µg/m^3 concentration. Lowest concentrations were observed at receptors D and F as 2.28µg/m^3 respectively.

Figure 5.6 depicts the isopleths for 24h NO_2 concentrations for the study area having six major receptors, viz., A, B, C, D, E and F. The model output predicted higher concentration at receptors C, B and A (5.30µg/m^3), which are institutional and residential areas respectively, followed by 0.8µg/m^3 concentration at receptor E, an ecological sensitive area. Again lowest concentrations were observed at D and F receptors as 0.3µg/m^3 and 0.1µg/m^3 respectively. In case of 1h averaging time, the high NO_2 emission level was concentrated to the nearby areas of emissions sources as compared to the 24h averaging time. In 24h averaging time the emission values gets reduced due to natural scavenging processes still the moderate level of emissions covered wide area in the predominant wind direction (South-East) .

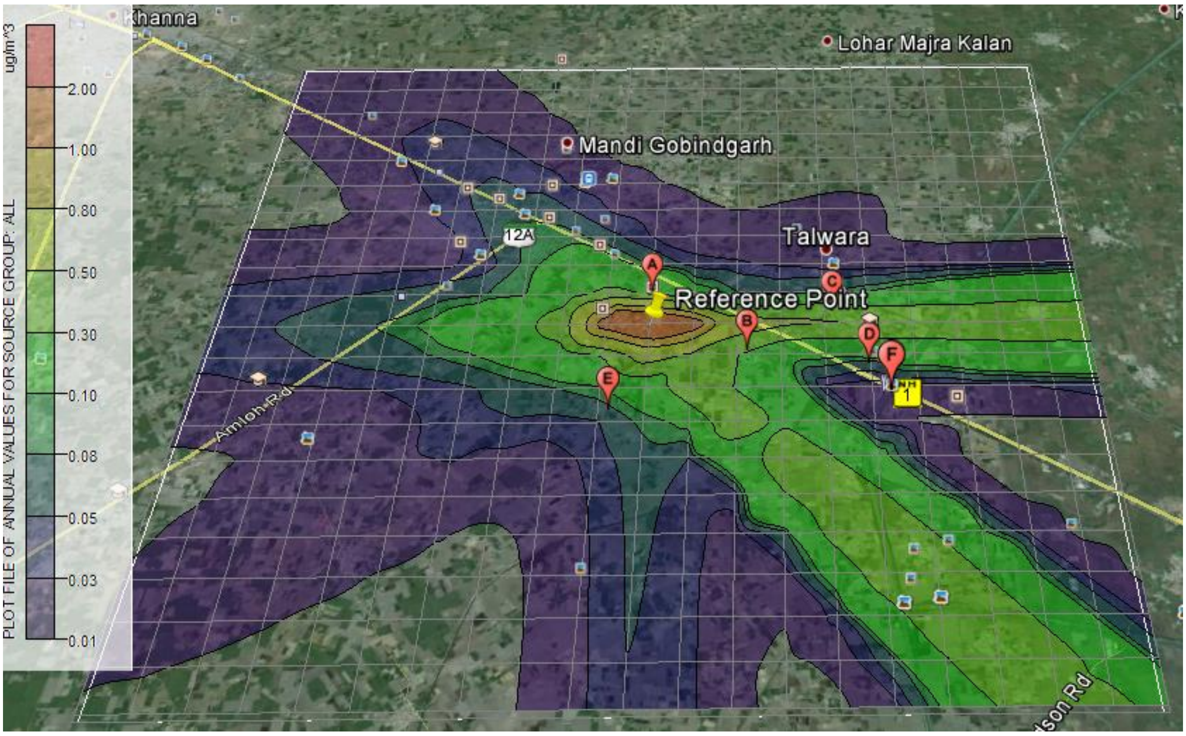

Figure 5.7 Isopleths showing dispersion of NO_2 for periodic averaging time

Figure 5.7 depicts the isopleths for periodic NO_2 concentrations in the entire study area. It covers of six major receptors, viz., A, B, C, D, E and F. The model output predicted higher concentration at receptors C and B (1.43µg/m^3) followed by at receptor A (0.2µg/m^3) residential area whereas lowest concentrations of 0.6 µg/m^3, 0.6 µg/m^3 and 0.02 µg/m^3 at D, F and E receptors respectively. In periodic average time of NO_2 emission, the area covered by the high and moderate level concentrations gets reduced due to the natural scavenging processes (precipitation, dispersion and deposition etc.).

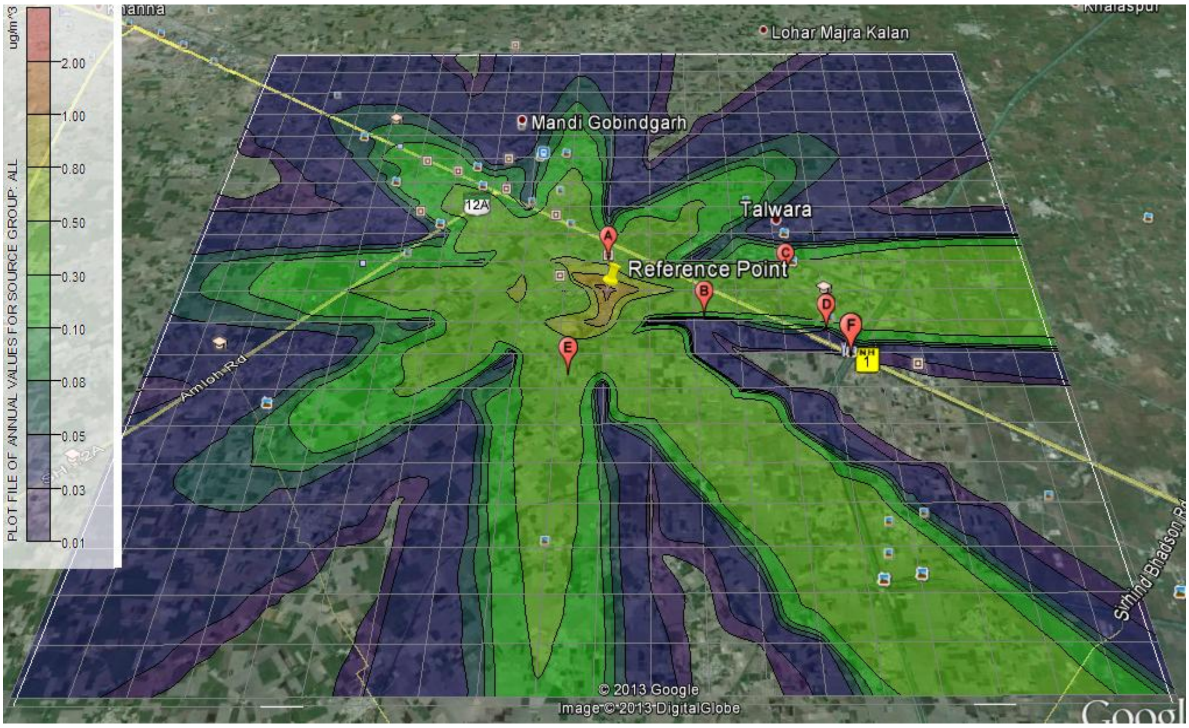

Figure 5.8: Isopleths showing dispersion of SO_2 for 1h averaging time

Figure 5.8 depicts the isopleths for 1 h SO_2 concentrations in the entire study area. It covers of six major receptors, viz., A, B, C, D, E and F. The model output predicted higher concentration 0.45µg/m^3 at receptor A which is a residential area, followed by 0.25µg/m^3 concentration at E and C receptors. The lowest concentration of 0.025µg/m^3 at B, D and F receptors. For 1h averaging time the emissions of SO_2 were low as compared to NO_2 but the area covered by the high emission concentration was more hence, the SO_2 emissions sources must be checked time to time.

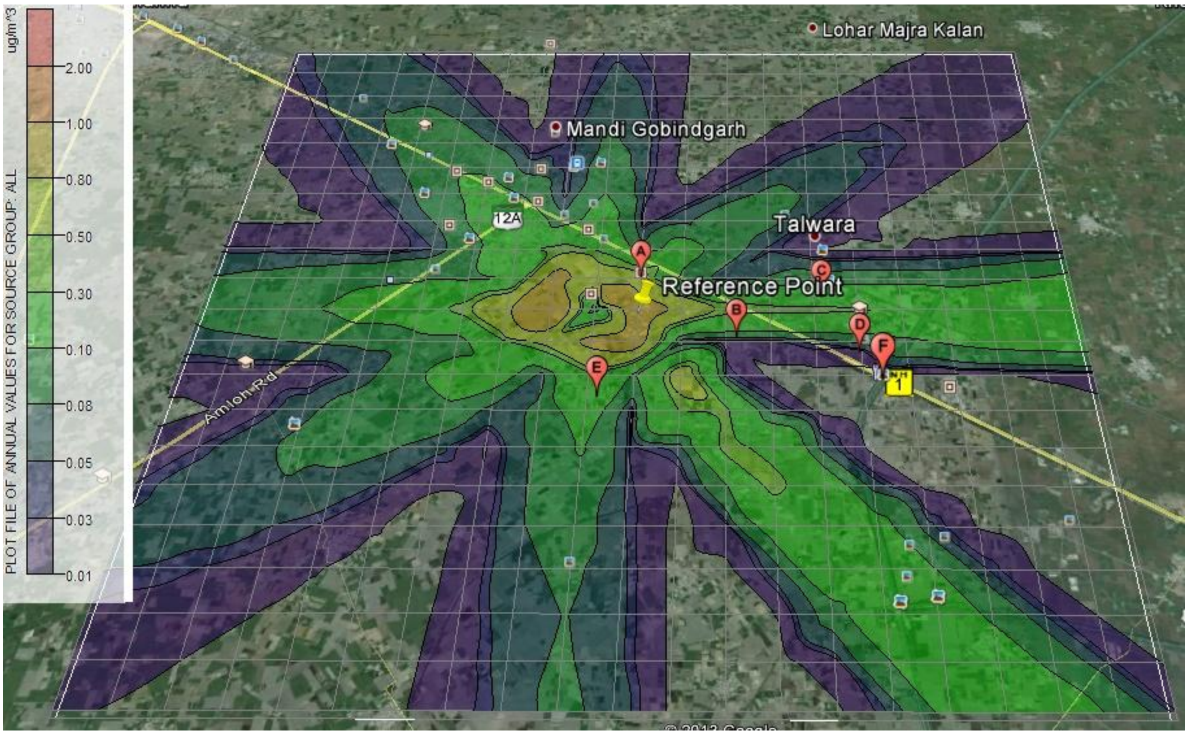

Figure 5.9: Isopleths showing dispersion of SO_2 for 24h averaging time

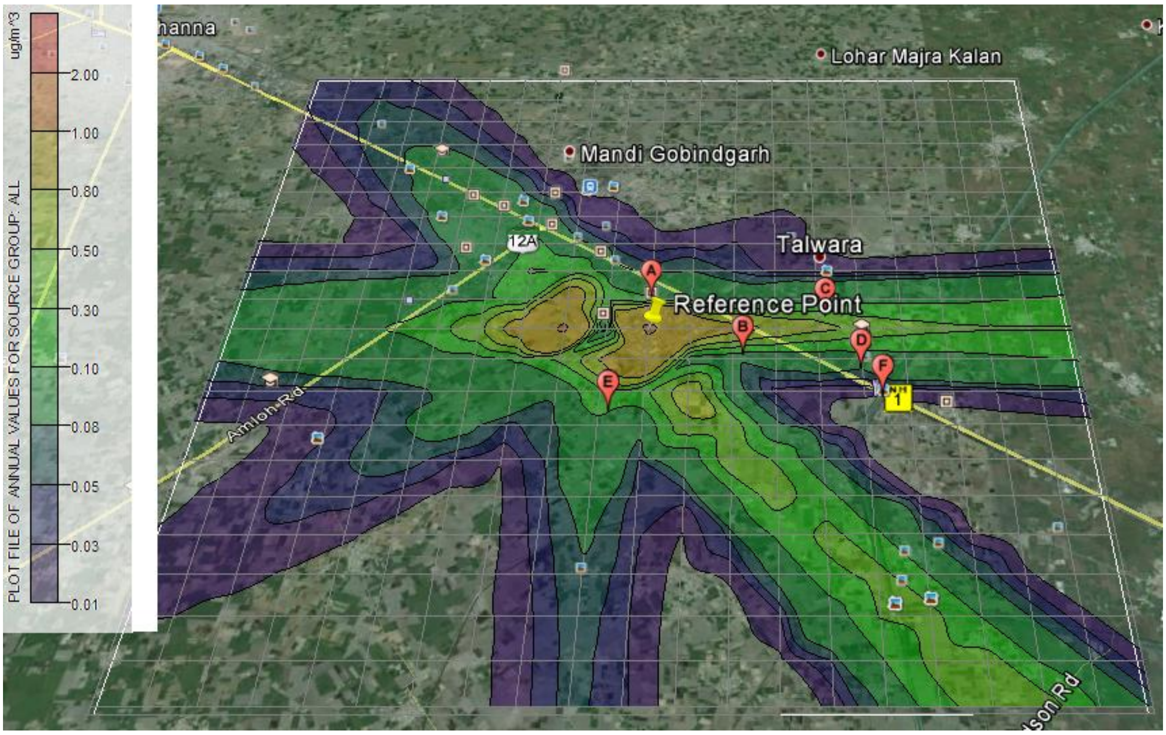

Figure 5.10: Isopleths showing dispersion of SO_2 for periodic averaging time

Figure 5.9 depicts the isopleths for 24 h SO_2 concentrations in the entire study area. It covers of six major receptors, viz., A, B, C, D, E and F. The model output predicted higher concentration of 0.20µg/m^3 at receptor A which is a residential area, followed by concentration of 0.035µg/m^3 at E and C receptors. And lowest concentration of 0.0035µg/m^3 was predicted at B, D and F receptors. For 24h averaging time the maximum concentration value was reduced due to scavenging processes but it covered wide area with high level concentration. The emission was concentrated in the predominant wind direction (South-East) i.e. to receptor A, E and C.

Figure 5.10 depicts the isopleths for periodic average time of SO_2 concentrations for the study area including six major receptors, viz., A, B, C, D, E and F. The model output predicted higher concentration of 0.03µg/m^3 at receptor C, followed by receptors A and E having concentration of 0.004µg/m^3. Again lowest concentrations were predicted at E, D and F receptors i.e. 0.002µg/m^3, 0.0017µg/m^3 and 0.004µg/m^3 respectively. The value of highest concentration for periodic time was less as compared to 1h and 24 h but the area covered by the high level concentration was much wider in case of periodic averaging time as compared to 1h and 24h. Hence, SO_2 remains for longer time in the atmosphere as compared to the NO_2.

Althogh, the predicted emissions of NO_2 and SO_2 seems to be within the limits of NAAQS Standards (i.e. 40µg/m^3 for NO_2 and 50µg/m^3 for SO_2 annually), but there are certain limiting factors like number of stacks considered for the total emissions which accounts for about 10% of the total 404 industries in the industrial hub of Mandi Gobindgarh, Moreover, vehicular and agricultural burning emissions were not included in the study. So, the predicted air quality scenario would be even worse, had all the sources would have been accounted.

5.3 Validation of AERMOD Model

Table 5.2: Validation of AERMOD

Locations	NO_2			SO_2		
	Predicted values for 24hr. ($\mu g/m^3$)	Measured Values for 24hr. ($\mu g/m^3$)	Normalized Mean Square Error (NMSE)	Predicted values for 24hr. ($\mu g/m^3$)	Measured Values for 24hr. ($\mu g/m^3$)	Normalized Mean Square Error (NMSE)
RIMT College	6.3064	10.29	0.24	0.20171	4.45	20.10

The model had been validated with observed pollutant concentrations at RIMT College receptor site. Air monitoring was carried out for the study period (May 2012 to April 2013) at periodic intervals (once every three months) for 24h duration using HVS along with impinge train. In order to have confidence in the results from such simulations, statistical analysis (NMSE) was performed. Uncertainties related to emission inventories at some locations lead to difference between predicted and measured values and also model predicts concentrations averaged over a certain volume, whereas measurements are made at a point having contribution of all types of emission sources (including vehicular and residential). In this study only representative stacks were considered. Hence, Observed values were high for NO_2 and SO_2 pollutants than model predictions. However, model gives more correlated and error free predictions for NO_2 but it under predicts highly for SO_2, which was similar to findings in studies done previously on AERMOD *(Namdeo et al., (2012).*

CONCLUSION

Stack monitoring campaign was carried out at periodic intervals, such as once every three months at the peak working hour of the industry through-out the study period of one year i.e. May 2012 to April 2013 in an industrial area (Focal point) Mandi Gobindgarh. The average emissions of SO_2 and NO_2 measured from representative stacks were taken to compile the emission inventory. The essential meteorological data like wind speed, wind direction, ambient air temperature, relative humidity, rainfall, atmospheric pressure, cloud cover, ceiling height and solar radiation were collected for daily mean hourly data through-out the study period with the help of Weather Monitoring Station and IMD, Patiala. Meteorological data then compiled in an excel file for further processing by AERMET and wind rose diagram and surface and profile file for the area has been generated. It was observed that the pre-dominant wind direction is from West with 59.87 % frequency of calm winds and the wind speed was 2.95 Knots. AERMOD was run for 1h, 24h and periodic average time to generate isopleths showing areas of minimal to high concentrations at six sensitive receptors, viz., A (Ajnali residential area), B (Ambe Majra residential area), C (RIMT College), D (PPCB), E (Chattarpur Zoo) and F (Floating restaurant). In case of 1h average time for NO_2 emissions, highest concentration of 11.87µg/m^3 at receptor C and lowest concentrations of 2.287µg/m^3 at D and F respectively were predicted. In case of 24h average time for NO_2 emissions, highest concentration of 5.3µg/m^3 at receptor C, B and A and lowest concentrations of 0.3µg/m^3 and 0.1µg/m^3 at D and F respectively were predicted. In case of periodic average time for NO_2 emissions, highest concentration of 1.43µg/m^3 at receptor C and B and lowest concentrations of 0.6µg/m^3, 0.6µg/m^3 and 0.02µg/m^3 at D, F and E respectively were predicted. But in this study only 10 % of the industrial emissions were covered. In case of 1h average time for SO_2 emissions, highest concentration of 0.451µg/m^3 at receptor A and lowest concentrations of 0.025µg/m^3 at D, B and F receptors were predicted. In case of 24h average time for SO_2 emissions, highest concentration of 0.21µg/m^3 at receptor A and lowest concentrations of 0.035µg/m^3 at E and C receptors were predicted. In case of periodic average time for SO_2 emissions, highest concentration of 0.0339µg/m^3 at receptor C and lowest concentrations of 0.002µg/m^3, 0.0017µg/m^3 and 0.004µg/m^{3}at E, D and F receptors were predicted. But in this study only 10 % of the industrial emissions were covered. Hence the actual emission scenario would be even worse than predicted from this simulation.

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ANNEXURE I

Revised National Ambient Air Quality Standards (2009-2010

S.No.	**Pollutant**	**Time Weighted Average**	**Concentration in Ambient Air**		
			Industrial, Residential, Rural and Other Area	**Ecologically Sensitive Area (notified by Central Govt.**	**Methods of Measurement**
1	Sulphur Dioxide (SO_2), µg/m^3	Annual 24 hours	50 80	20 80	**-** Improved West and Gaeke -Ultraviolet fluorescence
2	Nitrogen Dioxide (NO_2), µg/m^3	Annual 24 hours	40 80	30 80	- Modified Jacob & Hochheiser (Na-Arsenite) -Chemiluminescence
3	Particulate Matter (<10µ), µg/m^3	Annual 24 hours	60 100	60 100	- Gravimetric -TOEM - Beta attenuation
4	Particulate Matter (<2.5µ), µg/m^3	Annual 24 hours	40 60	40 60	- Gravimetric - TOEM - Beta attenuation
5	Ozone (O_3), µg/m^3	8 hours 1 hour	100 180	100 180	- UV photometric - Chemilminescence - Chemical Method

6	Lead (Pb), µg/m^3	Annual	0.50	0.50	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper
		24 hours	1.0	1.0	- ED-XRF using Teflon filter
7	Carbon Monoxide (CO), mg/m^3	8 hours	02	02	- Non Dispersive Infra Red (NDIR) spectroscopy
		1 hour	04	04	
8	Ammonia (NH$_3$), µg/m^3	Annual	100	100	- Chemiluminescence
		24 hours	400	400	- Indophenol blue Method
9	Benzene (C$_6$H$_6$), µg/m^3	Annual	05	05	- Gas chromatography based continuous analyzer -Adsorption and Desorption followed by GC analysis
10	Benzo(a)Pyrene (BaP)- particulate phase only, ng/m^3	Annual	01	01	- Solvent extraction followed by HPLC/GC analysis
11	Arsenic (As), ng/m^3	Annual	06	06	- AAS /ICP method after sampling on EPM 2000 or equivalent filter Paper
12	Nickel (Ni), ng/m^3	Annual	20	20	- AAS /ICP method after sampling on EPM 2000 or equivalent filter Paper

* Annual arithmetic mean of minimum 104 measurements in a year at a particular site taken twice a week 24 hourly at uniform intervals.

** 24 hourly or 08 hourly or 01 hourly monitored values, as applicable, shall be complied with 98% of the time in a year. 2% of the time, they may exceed the limits but not on two consecutive days of monitoring.

Note: Whenever and wherever monitoring results on two consecutive days of monitoring exceed the limits specified above for the respective category, it shall be considered adequate reason to institute regular or continuous monitoring and further investigation.