

Comparison of Dispersion Models in the Assessment of Air Quality due to Vehicular Emissions

A Dissertation

*Submitted in partial fulfilment of the requirements
for the award of degree of*

**Master of Technology
in
Environmental Science and Technology**

Submitted
By

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July 2015**

DECLARATION

I, the undersigned, hereby declare that the research work presented in thesis entitled “**Comparison of Dispersion Models in the Assessment of Air Quality due to Vehicular Emissions**” has been carried out under the supervision of **Dr. Amit Dhir**, Assistant Professor, School of Energy and Environment, Thapar University, Patiala.

Further, I declare that no part of this Dissertation been submitted for a degree or any other qualification of any other University or examining body in India/elsewhere.

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CERTIFICATE

This is to certify that work embodied in thesis entitled "**Comparison of Dispersion Models in the Assessment of Air Quality due to Vehicular Emissions**" submitted by Ms. Upasana Goyal in partial fulfilment of the requirements for the award of Master of Technology degree in Environmental Science and Technology at Thapar University, Patiala is an authentic work carried out by her under our supervision and guidance.

To the best of our knowledge, the matter presented in this thesis has not been submitted in part or full, to this or any other University / Institute for award of any degree or diploma.


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ABSTRACT

India has made rapid development in industrialization and it is one of the ten most industrialized nations of the world. Increase in technological, industrial and agricultural advancement, coupled with increase in population growth and this development has brought with it surplus and unforeseen consequences such as unplanned urbanization, pollution in terms of generation of noxious gases and particulate emissions and various health impact. Transportation sector, especially the road transportation sector, is one of the key components of economic growth of a country. Road transportation sector in India has registered a sustainable growth rate of 9.9% over the last decade. The total number of registered motor vehicles has increased from about 21.4 million in 1991 to about 142 million in 2011. The rapidly growing vehicle fleet, distance travelled by each vehicle type and change in land use pattern are some of the primary causes of air pollution and consequently deteriorating air quality. The process of burning gasoline to power cars and trucks contributes to air pollution by releasing a variety of emissions into the atmosphere such as carbon monoxide (CO), nitrogen and sulphur oxides, particulate matter and respirable particulate matter, lead, benzene and hydrocarbons.

In the present study, the comparison of two air quality dispersion models has been assessed in predicting the air quality by taking into account the emissions from line source. The emission inventory was prepared for Patiala city. 17 roads (links) covering major areas of the city were studied for traffic monitoring in order to know the vehicular composition and volume of the road to calculate the combined contribution of both diesel and petrol driven vehicles in the air quality of the city. Out of 17 links, 4 links were self monitored for vehicular traffic in the months of January-April, 2015 fortnightly. Mean hourly meteorological data was collected for the months of January-April, 2015 from Weather monitoring Station which was imported to AERMET. Based on wind data, population density, topography and other local parameters of study area receptor was selected on which maximum Ground Level Concentrations (GLC) of CO, NO₂ and PM were predicted by using dispersion models. The spatial distribution of the maximum incremental concentration for line source shows AERMOD predicted higher incremental concentrations in downwind direction than CALINE4 in both 17 links and 4 links studies for all the vehicular pollutants for 1 h averaging period.

Validation of models prediction with ambient air measurements was done for both CALINE4 and AERMOD for 4 self monitored links using various statistical descriptors i.e. $NMSE \leq 1.5$; $-2 \leq FB \leq 2$ and $0.5 \leq FAC2 \leq 2$. CALINE4 model fulfils all the criteria for model acceptance. AERMOD over predicts the ground level concentrations for all the pollutants also PM and NO₂ concentrations are exceeding the prescribed standards. This is probable because of not considering the effect of building downwash and hourly variable emission rates. Thus, CALINE4 model is more validate and accurate in predicting ground level concentrations of near road pollutants.

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CHAPTER 1

INTRODUCTION

1.1 Overview

Pollution is a problem that human invent due to various anthropogenic activities. Air pollution is one such form that refers to the contamination of the air, irrespective of indoors or outside. Every day, the average person inhales about 20,000 liters of air. Every time we breathe, we risk inhaling dangerous chemicals that have found their way into the air. Air pollution is a complex problem that plays a key role in human well-being, environment and climate change. Air pollution can contain a mixture of solid particles, liquid droplets and gases from a variety of sources such as industry, motor vehicles, heating appliances, and tobacco smoke etc. It can also be generated by natural events such as bush fires and can contain windblown dust, pollen and mould spores. The composition of air pollution can vary greatly, depending on the season, the weather, the types and numbers of sources. Air quality, both indoor and outdoor, is affected by the type of energy use to power businesses and the equipment. Cleaning supplies, paint, adhesives or printer cartridges, for example, can release volatile organic compounds or other dangerous pollutants into the indoor air. An energy-guzzling cooling system requires power plants to burn more coal for electricity, generating more air and global warming pollution. Older diesel trucks and equipment can emit more than ten times as much soot pollution as new models and can usually be retrofit to be reduced their pollution before they are replaced. By reducing waste, purchasing energy-efficient and low-emission equipment and choosing products that minimize the release of harmful pollutants can reduce both indoor and outdoor air pollution.

1.2 Air quality Worldwide

The levels of air pollutants are rapidly increasing in urban and rural areas. Most Asian cities don't comply with the WHO air quality guidelines or the US Environmental Protection Agency standards; exceptions are cities in more developed countries such as Singapore, Taiwan and Japan. Several Asian cities in China, India and Vietnam have the highest levels of outdoor air pollution in the world (*Chen su et al.,2011*). These pollutants can lead to serious public health problems, including asthma, irritation of the lungs, bronchitis, pneumonia, decreased resistance to respiratory infections, and premature death. Since approximately half the population of the

world lives in medium to large cities, it is essential to evaluate the air quality levels of the atmosphere in order to assess the possible health impact from exposition to pollutants estimates that air pollution contributes to approximately 800,000 deaths and 4.6 million lost life years annually (*World Health Organization [WHO], 2002*). Motor vehicles emit particulate matter (PM), NO₂ and NO (together referred as NO_x), carbon monoxide, organic compounds and lead. Developing nations are particularly affected by air pollution; as many as two thirds of the deaths associated with air pollution on a global scale occur in Asia (*Cohen et al., 2004*).

In April 2014, The World Health Organization issued new information estimating that outdoor air pollution was responsible for the deaths of some 3.7 million people under the age of 60 in 2012. Only 12% of the people living in cities reporting on air quality reside in cities where this complies with WHO air quality guideline levels. About half of the urban population being monitored is exposed to air pollution that is at least 2.5 times higher than the levels WHO recommends, putting those people at additional risk of serious, long-term health problems. The organization also emphasized that indoor and outdoor air pollution, combined, are among the largest risks to health worldwide. Many factors contribute to this increase, including dependence on fossil fuels such as coal fired power plants, private transport motor vehicles, inefficient use of energy in buildings, and the use of biomass for cooking and heating. Measurement of fine particulate matter of 2.5µm or less in diameter (PM_{2.5}) is considered to be the key indicator of the level of health risks from air pollution.

1.3 Air quality status in India

Rapid industrialization, urbanization and population growth especially in the last decade have adversely affected urban climate, air quality and caused imbalances in the regional climate at large. Air pollution in India has increased rapidly because of intensive population growth, increase in the numbers of vehicles, use of fuels with poor environmental performance, badly mentioned transportation systems, poor land use pattern, industrialization, and above all, ineffective environmental regulations (*Chattopadhyay et al., 2010*). The latest WHO urban air quality database covers 1,600 cities across 91 countries and it reconfirms that most Indian cities are becoming death traps because of very high air pollution levels and appears among the group of countries with highest particulate matter (PM) levels. Therefore, there is a need for timely information about changes in the pollution level. A study conducted by the World Bank indicates premature deaths of people in Delhi owing to high levels of air pollution (*CPCB, 2003*).

The PM10 and PM2.5 database released by WHO contains data of 124 Indian cities. Analysis of this database indicates that all Indian cities exceed the WHO guideline of $20 \mu\text{g}/\text{m}^3$ for PM10, in case of PM2.5 except one city (Pathanamthitta in Kerala is at the WHO guideline limit of 10), all exceed the WHO guideline of $10 \mu\text{g}/\text{m}^3$. The PM2.5 levels are worst in Delhi and Patna, exceeding the WHO guideline by about 15 times, followed by Gwalior, Raipur, Ahmedabad, Lucknow and Ferozabad, all exceeding the safe levels by 9 to 14 times. Cities such as Kanpur, Amritsar, Ludhiana, Allahabad, Agra, Jodhpur, Dehradun and Chandrapur closely follow the above-mentioned hot spots. Major factors responsible are increased combustion of fossil fuels in coal fired power plants, transport motor vehicles and the use of biomass for cooking and heating. Air pollutants whether man made or natural are to be monitored to know their characteristics and concentration in the ambient air. Keeping this in view, Central Pollution Control Board executed a nation-wide programme of ambient air quality monitoring known as National Air Quality Monitoring Programme (NAMP) in year 1984. The network consists of three hundred and forty two (342) operating stations covering one hundred and twenty seven (127) cities/towns in twenty six (26) states and four (4) Union Territories of the country.

The major objectives of the N.A.M.P. is to determine status and trends of ambient air quality, to ascertain whether the prescribed ambient air quality standards are violated, to Identify Non-attainment Cities, to obtain the knowledge and understanding necessary for developing preventive and corrective measures and to understand the natural cleansing process undergoing in the environment through pollution dilution, dispersion, wind based movement, dry deposition, precipitation and chemical transformation of pollutants generated.

Under N.A.M.P., four air pollutants i.e. Sulphur Dioxide (SO_2), Oxides of Nitrogen as NO_x , Suspended Particulate Matter (SPM) and Respirable Suspended Particulate Matter (RSPM / PM10) have been identified for regular monitoring at all the locations. The monitoring of meteorological parameters such as wind speed and wind direction, relative humidity (RH) and temperature were also integrated with the monitoring of air quality.

The monitoring is being carried out with the help of Central Pollution Control Board, State Pollution Control Boards, Pollution Control Committees, National Environmental Engineering Research Institute (NEERI), Nagpur. CPCB co-ordinates with these agencies to ensure the uniformity, consistency of air quality data and provides technical and financial support to them for operating the monitoring stations.

In the various findings by N.A.M.P. it was reported that SO₂ and NO₂ levels are within the prescribed NAAQS in residential areas of all the cities. Decreasing trend may be due to use of cleaner fuel such as CNG in Delhi, implementation of Bharat Stage-III emission norms and commensurate fuel quality, change in domestic fuel used from coal to LPG. But RSPM levels exceed prescribed NAAQS in residential areas of many cities. The reason for high particulate matter levels may be vehicles, engine gensets, small scale industries, biomass incineration, resuspension of traffic dust, commercial and domestic use of fuels, etc. High levels of CO might be attributed to increase in vehicular population especially passenger cars in Delhi.

The RSPM concentrations are higher in winter season and are lower during monsoon months. A plausible explanation for these observations may be found by examining meteorological conditions. During the winter season, average mixing height is lower as compared to other seasons and atmospheric dispersion is typically at a minimum and therefore the pollutants will not be as widely dispersed. Lower average mixing height in winter season results in less volume of troposphere available for mixing and hence, higher concentrations of pollutants prevail. Calm conditions in winter season result in less dispersion of pollutants resulting in building up their levels. The monsoons results in large amount of precipitation, high wind velocities and changes in general wind direction. The large amounts of precipitation reduce atmospheric pollution via associated wet deposition processes. Further wind velocities will allow for pollutant transport away from sources and increase mixing processes, thereby resulting in lower levels (*CPCB 2008*).

National Ambient air quality standards (NAAQS) - 2009 through Government Gazette are annexed for reference (Annexure I).

1.4 Vehicular emission and Air quality

The road emissions are the major source of air pollution in urban areas with subsequent adverse health effects. Although, the improvements in vehicle technologies have played a significant role in reducing traffic emissions at the source, air pollution abatement still remains a challenge in cities. Increasing demand of transportations due to economic growth has triggered a boom in the number and use of motor vehicles. Owing to rapidly increasing numbers of motor vehicles and limited use of emission control technologies, vehicular emissions are responsible for about 70% of air pollution in Indian cities.

Today, majority of the cars and trucks use internal combustion engines that burn gasoline or other fossil fuels like CNG, Diesel etc. The process of burning fuel to power cars and trucks contributes to air pollution by releasing a variety of emissions into the atmosphere. Emissions that are released directly into the atmosphere from the tailpipes of cars and trucks are the primary source of vehicular pollution. While new cars and light trucks emit about 90 percent fewer pollutants than they did three decades ago, total annual vehicle-miles driven have increased by more than 140 percent since 1970. The emission reductions from individual vehicles have not adequately kept pace with the increase in miles driven and the market trend toward more-polluting light trucks, a category that includes sports utility vehicles (SUVs). As a result, cars and light trucks are still the largest single source of air pollution in most urban areas, accounting for one quarter of emissions of smog-forming pollutants nationwide. The other factors of vehicular pollution in the urban areas are 2-stroke engines, poor fuel quality, old vehicles, inadequate maintenance, congested traffic, poor road condition and old automotive technologies and traffic management system. Delhi has more vehicles than Mumbai, Kolkata and Chennai put together. Unfortunately, number of vehicles in Delhi outpaces the road length. Delhi's total road length was 8,380 km in 1971 which increased to 25,948 km in 2004. Thus whereas the road length increase only by three times, the number of vehicles increased by over twenty times. Major air pollutants associated with motor vehicles and their health impacts are given Table 1.1.

Table 1.1: Vehicular pollutants and its Health Impacts

Pollutant	Effect on Human Health
Carbon Monoxide	Affects the cardio vascular system, exacerbating cardiovascular disease symptoms, particularly angina; may also particularly affect fetuses, sick, anemic and young children, affects nervous system impairing physical coordination, vision and judgments, creating nausea and headaches, reducing productivity and increasing personal discomfort.
Nitrogen Oxides	Increased susceptibility to infections, pulmonary diseases, impairment of lung function and eye, nose and throat irritations.
Sulphur Dioxide	Affect lung function adversely.
Particulate Matter and Respirable Particulate Matter (SPM and RPM)	Fine particulate matter may be toxic in itself or may carry toxic (including carcinogenic) trace substance, and can alter the immune system. Fine particulates penetrate deep into the

	respiratory system irritating lung tissue and causing long-term disorders.
Lead	Impairs liver and kidney, causes brain damage in children resulting in lower I.Q., hyperactivity and reduced ability to concentrate.
Benzene	Both toxic and carcinogenic. Excessive incidence of leukemia (blood cancer) in high exposure areas.
Hydrocarbons	Potential to cause cancer

The union government enacted a revised Motor Vehicle Act in 1990, making emission regulations a federal government responsibility. India has established limits on carbon monoxide emissions (at idle) for gasoline-fueled cars, motorcycles, and three-wheelers. New emission standards for gasoline-fueled cars took effect in 1991. Emissions from diesel vehicles came under control in 1992 based on ECE R49 regulations. Vehicle emission norms were set for the first time in 1990's when the government under the Supreme Court order introduced Euro norms in 1999. Later, it was replaced by Bharat Stage Emission standards. Under the Bharat Stage IV norms which are in turn based on Euro IV norms, Bharat Stage-IV, CO should be 1.0 (g/km) and HC+NOx (g/km) should be 0.18 (combined) as per CPCB.

The implementation has, however, suffered from certain limitations such as the need for retro fitting of catalytic converter and other devices on older systems in use. New vehicles and systems come with these devices but the bottleneck is that the process gets hampered in the presence of lead/sulphur. So to counter this, the fuel needs to have less of lead and sulphur. In India, this has been achieved by selling unleaded fuel and placing a limit on amount of sulphur.

1.5 Description of study area and its air quality

Patiala district is one of the important historical districts located in eastern part of the Punjab. Patiala has been the important educational centre from the very beginning. A number of State and regional level offices and institutions of Punjab are located at Patiala. It is bounded by district Fatehgarh Sahib, S.A.S Nagar and Union Territory of Chandigarh in the North; district Sangrur in the West and Jind (Haryana State) in South and Ambala (Haryana) in the east. The district lies between north latitude 29° 49' to 30° 47' and east longitude 75°58' to 76°54'. The total area of the district according to village papers is 3,22,000 hectares. This district has 5 tehsils, 9 towns and 1084 villages as per the 2001 census. District Patiala has a population of 18,39,056

with a density of population in the district is 507 persons per sq km. It has an average elevation of 250 meters (820 feet). There are various kind of small scale to medium scale industries exists. Recent surveys of traffic indicate that most of the road network is not congested. Only four roads namely one from Fountain chowk to Leela Bhawan, second from Thapar University to Gurudwara Dukhniwaran Sahib, third from Fountain chowk to Mohindra college (Lower Mall) and fourth from Gurudwara Dukhniwaran Sahib to Bus stand have Volume/Cpacity (V/C) ratio well in excess of 1 (*Master Plan L.P.A Patiala (Document of Government of Punjab 2011)*).

The main sources of air pollution in the Punjab are due to emissions from vehicles, industrial stacks, power plants, burning of fuel in domestic sector and burning of agricultural residues in the harvesting season in the fields by farmers. The Government of Punjab has declared the whole of the State as an Air Pollution Control Area and it is the responsibility of Punjab Pollution Control Board to ensure that the ambient air quality in the State is not deteriorated on account of air pollution caused by the various sources. Master Plan of Patiala city is shown in Figure 1.1.

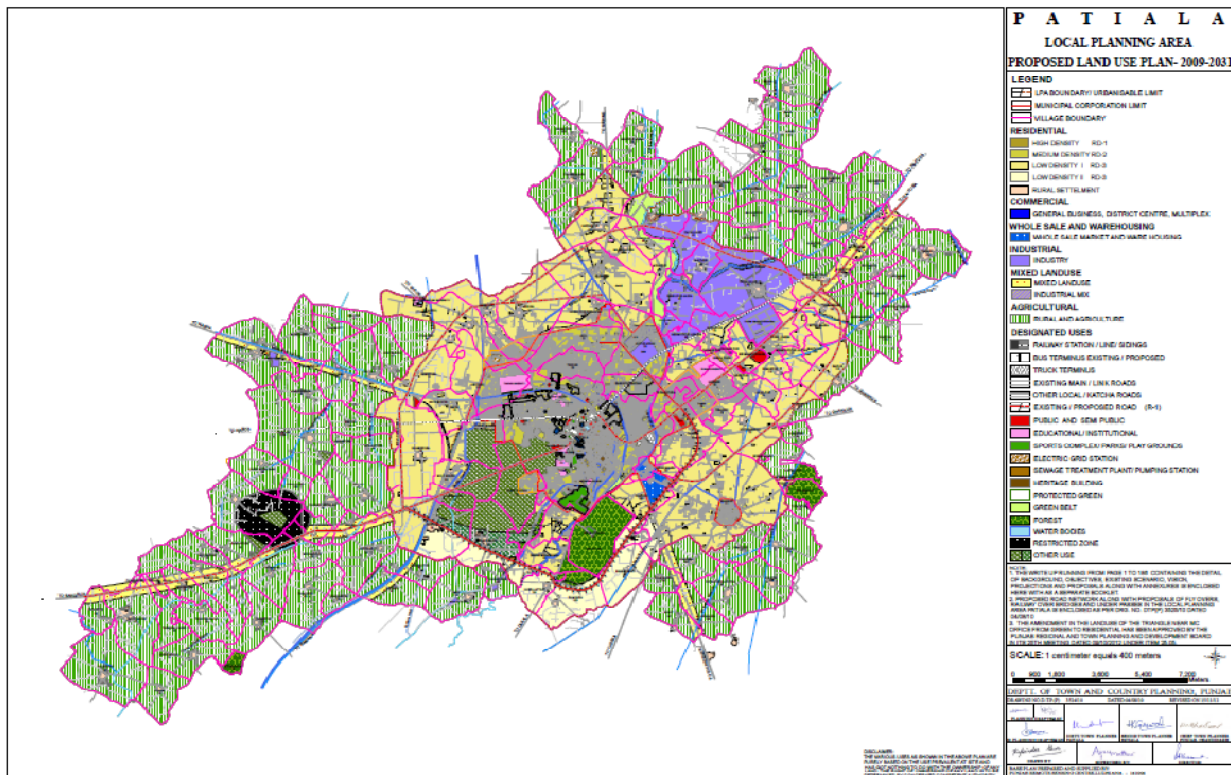


Figure 1.1: Master plan image of Patiala (Source: www.puda.nic.in)

During the year 2013-2014, the Board monitored the Ambient Air Quality by collecting 41480 ambient air samples at 24 monitoring stations in 11 cities. In Patiala, monitoring station was installed at 2 locations namely Ceylon Industries (Industrial Area) and Fire Brigade Office (Commercial Area). Patiala SO₂, NO_x and RSPM Annual Average Concentration for Patiala City during the year 2009- 2013 is given in Figure no. 1.2, 1.3 and 1.4 respectively.

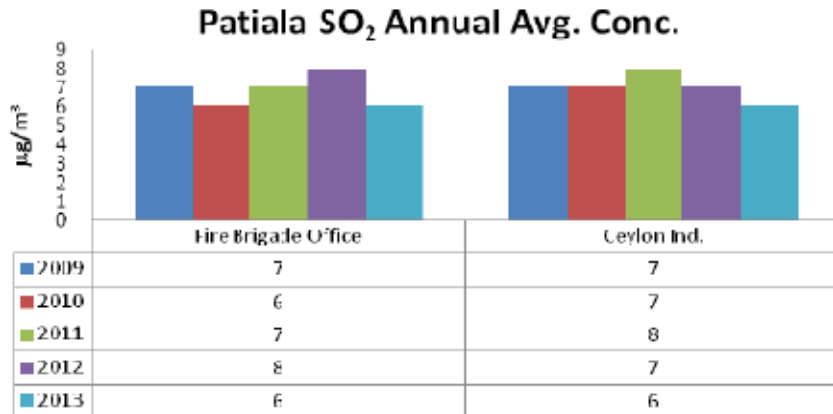


Figure1.2: Patiala SO₂ annual average concentrations during 2009-2013

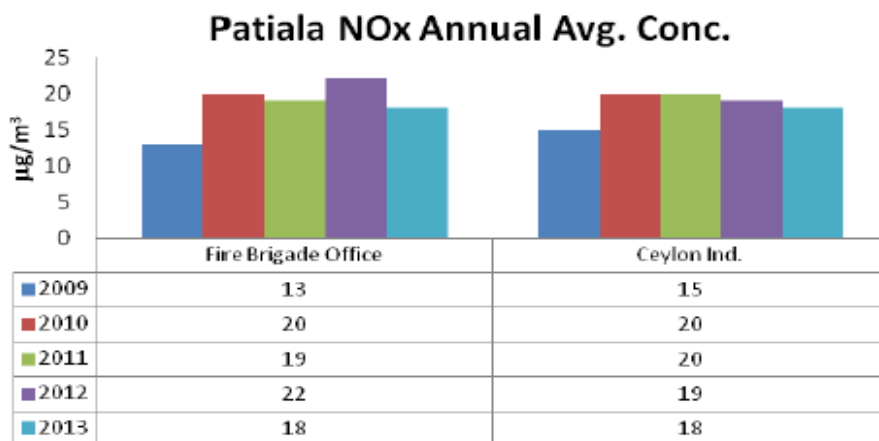


Figure1.3: Patiala NO_x annual average concentrations during 2009-2013

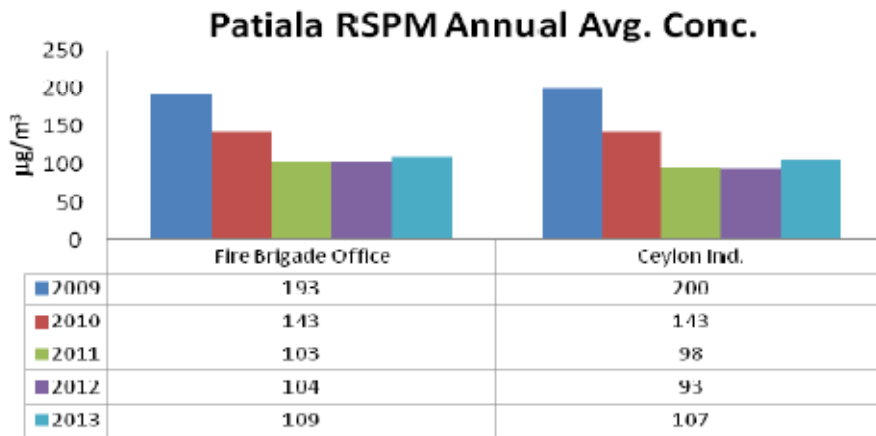


Figure1.4: Patiala RSPM annual average concentration during 2009-2013

In terms of air quality, though the ambient concentration of SO₂ and NO₂ is well within the norms yet, SPM levels far exceed the norms which may be attributed to the vehicular emissions and general road dust as per information provided by Punjab Pollution Control Board, Patiala (*Master Plan L.P.A Patiala (Document of Government of Punjab 2011)*).

CHAPTER 2

AIR QUALITY MODELING

Air pollution modeling is a numerical tool used to describe the causal relationship between emissions, meteorology, atmospheric concentrations, deposition, and other factors. Air pollution 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 pollution modeling, 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. Air quality model improve the limitations of monitoring networks by providing prediction of the temporal and spatial distribution of actual pollution levels. These models are important to our air quality management system because they are widely used by agencies tasked with controlling air pollution to both identify source contributions to air quality problems and assist in the design of effective strategies to reduce harmful air pollutants. For example, air quality models can be used during the permitting process to verify that a new source will not exceed ambient air quality standards or, if necessary, determine appropriate additional control requirements. In addition, air quality models can also be used to predict future pollutant concentrations from multiple sources after the implementation of a new regulatory program, in order to estimate the effectiveness of the program in reducing harmful exposures to humans and the environment. Based on inputs of meteorological data and source information, these models are designed to characterize primary pollutants that are emitted directly into the atmosphere and, in some cases, secondary pollutants that are formed as a result of complex chemical reactions within the atmosphere.

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 modeled 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. Therefore, modeling studies in combination with air quality monitoring are then essential and complementary tools for long and short term air pollution control strategies.

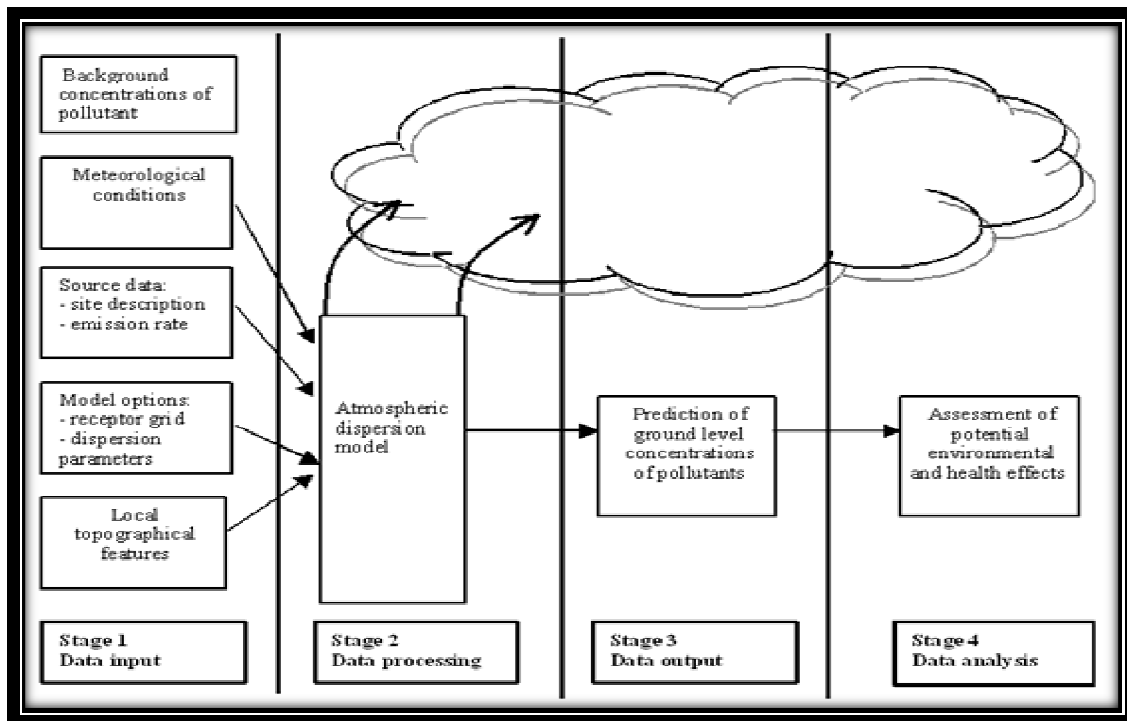


Figure 2.1: Four stages of Air Quality Modeling

2.1 History of Air Quality Modeling

One of the first challenges in the history of air pollution modeling (*Sutton, 1932*) was the understanding of the diffusion properties of plumes emitted from large industrial stacks. For this purpose, a very successful, yet simple model was developed – the Gaussian Plume Model. This model was applied for the main purpose of calculating the maximum ground level impact of plumes and the distance of maximum impact from the source. 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.

Line source dispersion has been studied since at least the 1960s, when the regulatory framework in the United States began requiring quantitative analysis of the air pollution consequences of major roadway and airport projects. By the early 1970s this subset of atmospheric dispersion models were being applied to real world cases of highway planning, even including some controversial court cases (*U.S. EPA*).

2.2 Classification of air quality 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 modeled 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 modeling region (e.g., a 50 kilometer 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, AERMOD and CALINE4.

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 require 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 modeling; 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).

2.3 Air Quality Models spatial scales

Pollutants dispersion in the atmosphere is through molecular diffusion, where matters move from a region of high concentration to a region of low concentration. However, apart from molecular diffusion, plumes spread due to other complex processes. These processes are mechanically and thermally generated turbulence and wind fluctuations. Due to difference in

process and extent of dispersion the predictive are categorized by applicable spatial scale. It is convenient to consider three spatial scales: local, meso to regional, and global (Reid et al., 2003).

2.3.1 Local scale

Local scale modeling is typically used to assess the impact of single sources, or small groups of sources, over distances ranging up to tens of kilometers. 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 modeled by assuming a Gaussian concentration shown in equation 1 distribution in the horizontal and vertical directions. The resulting concentration is then given by:

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

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 modeled 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 behavior under certain stability or boundary layer conditions, e.g., fanning, looping, fumigation, etc. and the effect of buildings on plume behavior. 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.

2.3.2 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). 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.

2.3.3 Global scale

Global models consider the transport of pollutants throughout the atmosphere, with no artificial restriction of the domain. To date, most global modeling has been confined to carbon dioxide and the climate change issue, which also means that chemical transformation, is not treated, further streamlining the computation.

2.4 Selection of air quality models

It is very important to select the model that meets the requirements of the task. No single model can handle all situations and range of applications. 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;
- 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 the technical expertise of user.

2.5 Data required for dispersion modeling

Dispersion models require two types of data inputs: information on the source or sources including pollutant emission rates, and meteorological data. In addition, they also need information on the topography of study area. The models then use this information to simulate mathematically the pollutants transport and dispersion. 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.

1. 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.

2. Physical/chemical characteristics of emissions: these data are closely related to emission rates (i.e., from measurements and/or emission factors). 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 speculated based on the emissions source type through the use of sources such as EPA's SPECIATE database.

3. Types of release point- The required input data, modeling approach, and model selected for assessment can depend on the type of release being modeled.

–**Point sources** (modeling sense) 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** (modeling sense) 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 modeled 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 modeled 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 modeled using special techniques or models depending on the characteristics of the emission source.

4. Release point parameters-Depending on the type of source being modeled, 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 modeled, provide concentration estimates at the nodes of the modeling grid that is initially laid out around the source.

5. 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 modeling that takes into account complex terrain (e.g., ground surfaces higher than release height elevation) will require terrain elevation data.

6. Chemical-specific data. If transformation/removal is being modeled, rates of transformation or removal for the chemicals being modeled are required.

7. Boundary or background concentrations. Ideally, emissions from modeled source(s) are responsible for the modeled concentrations. However, background concentrations, or boundary conditions in the case of grid models, may be important contributors to the total 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.

8. Meteorological conditions: Observed meteorological data for use in air quality modeling consist of physical parameters that are measured directly by instrumentation, and include temperature, dew point, wind direction, wind speed, cloud cover, cloud layer(s), ceiling height, visibility, current weather, and precipitation amount.

2.6 Dispersion Models

An atmospheric dispersion model is a mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere. It is the mean of estimating downwind air pollution concentration for given information about the pollutant emissions and nature of the atmosphere processes. These models use mathematical and numerical technique to simulate the physical and chemical processes that affect air pollutants as they disperse and react in the atmosphere. The objective is to estimate the concentration of a pollutant at a particular receptor point by calculating from some basic information about the source of the pollutant and the meteorological conditions.

The dispersion models used in the study were:

- AERMOD (American Meteorological Society/ Environmental Protection Agency Regulatory MODel).
- CALINE4 (California Line Source Dispersion Model Version 4).

2.6.1 AERMOD

AERMOD was developed for the regulatory purpose in 1991 by the AERMIC (American Meteorological Society (AMS)/United States Environmental Protection Agency (EPA) Regulatory Model Improvement Committee), a collaborative working group of scientists from the AMS and the EPA. On April 21 of 2000, the EPA proposed that AERMOD be adopted as the EPA's preferred regulatory model for both simple and complex terrain. On November 9 of 2005, AERMOD was adopted by the EPA and promulgated as their preferred regulatory model, effective as of December 9 of 2005. The entire developmental and adoption process took 14 years (from 1991 to 2005). It was intended as a replacement of the Industrial Source Complex Version 3 (ISC3) model. The AERMOD atmospheric dispersion modeling system is an integrated system that includes three modules:

- A steady-state dispersion model designed for short-range (up to 50 kilometers) dispersion of air pollutant emissions from stationary industrial sources.

- A meteorological data preprocessor (AERMET) that accepts surface meteorological data, upper air soundings, and optionally, data from on-site instrument towers. It then calculates atmospheric parameters needed by the dispersion model, such as atmospheric turbulence characteristics, mixing heights, friction velocity.
- A terrain preprocessor (AERMAP) whose main purpose is to provide a physical relationship between terrain features and the behavior of air pollution plumes. It generates location and height data for each receptor location. It also provides information that allows the dispersion model to simulate the effects of air flowing over hills or splitting to flow around hills.

An atmospheric dispersion model based on atmospheric boundary layer turbulence structure and scaling concept, including treatment of multiple ground level, elevated point, area and volume sources. It handles flat or complex, rural or urban terrain and includes algorithms for building effects and plume penetration of inversions aloft. It uses Gaussian dispersion for stable atmospheric conditions (i.e., low turbulence) and non-Gaussian dispersion for unstable conditions (eg. high turbulence). Algorithms for plume depletion by wet and dry deposition are also included in the model. AERMOD also includes PRIME (Plume Rise Model Enhancements) which is an algorithm for modeling the effects of downwash created by the pollution plume flowing over nearby buildings.

2.6.2 CALROADS

CALRoads View is an air dispersion modeling package for predicting air quality impacts of pollutants near roadways. CALRoads View combines the following mobile source air dispersion models into one seamless integrated graphical interface: CALINE4, CAL3QHC, and CAL3QHCR. These US EPA models are used for predicting air pollution concentrations of carbon monoxide (CO), nitrogen dioxide (NO₂), particulate matter (PM), and other inert gases from idle or moving motor. It has 3 in 1 integrated model interface:

1. CALINE4: CALINE-4 model is a fourth-generation line source air quality dispersion model that is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion in the proximity of roadways. The model employs source strength, meteorology, site geometry and site characteristics as input parameters and predicts pollutant concentrations for receptors located within 150 meters either side of the roadways. The CALINE-4 model allows road to be broken into multiple links that can vary in traffic volume, emission rates, height, width, etc. CALINE-4 is

capable of specifying links at heights above grade ($z = 0$), links as bridges (allowing air to flow above and below the link) and links as parking lots (which should be defined by the user as having a height of zero). Also, unlike CAL3QHCR, CALINE-4 is capable of analyzing the dispersion of pollutants in wind speeds of less than 1 m/s. In addition, Caltrans makes available to users a simplified version of CALINE-4. The limitation of CALINE-4 includes a feature for analyzing the effects of nearby canyons or bluffs on pollutant dispersion and is only recommended for use in rare circumstances by very experienced modelers. The concentration at a point with coordinates (x, y, z) is calculated based on the following equation:

$$C(x, y, z, H) = \frac{Q}{2\pi u \sigma_z \sigma_y} * \left[\exp - \left(\frac{y^2}{2\sigma_y^2} \right) \right] \left[\exp \frac{-(z - H^2)}{2\sigma_z^2} \right] + \exp \left[\frac{-(z + H^2)}{2\sigma_z^2} \right]$$

C = Concentration of the pollutant in air [m/L³]

Q = Rate of chemical emission [m/T]

U = Wind speed in X direction. [L/T]

y = Standard deviation in y direction.[L]

σ_z = Standard deviation in z direction.[L]

σ_y = Distance along a Horizontal axis perpendicular to the wind. [L]

z = Distance along a vertical axis. [L]

H = effective stack height. [L]

2. CAL3QHC: CAL3QHC is a multi-source model and was developed by the U.S. EPA in 1990. CAL3QHC was intended to be used for estimating vehicle emissions near roadway intersections, specifically for CO. Although, it can also be used for analyzing other inert type of pollutants such as particulate matters. CAL3QHC is based on the same line source dispersion algorithm as used in CALINE3, with an added algorithm to provide simple vehicle queuing estimates. According to the CAL3QHC user's guide, CALINE3 was designed to predict emissions from vehicles under free-flow conditions but does not account for emissions from idling vehicles. The queuing theory added to CALINE3 to produce CAL3QHC reportedly allows for the consideration of idling vehicle emissions

by estimating queue lengths. The CAL3QHC can accommodate up to 120 road links, each of which can be specified as either a free flow or queued link. The program allows for 60 receptor sites and automatically sums the contribution of all links to each receptor site. Link widths should include 10 feet on either side of the traveled roadway to include vehicle plume interactions. But, there is also a limitation of this model that does not allow link width to be greater than the link length and wind speed must be greater than 1 m/s. CAL3QHC is not intended for modeling sites with complex geometries, topography or atmospheric instability. Additionally, CAL3QHC is also not valid for analysis of link heights greater than 30 feet. The CAL3QHC model estimates total air pollutant concentrations (CO or PM) near highways from both moving and idling vehicles. This model also estimates the length of queues formed by idling vehicles at signalized intersections.

3. CAL3QHCR: CAL3QHCR is intended to be a more refined version of CAL3QHC. This model uses meteorological data for one year (on-site) or five year (local airport) period rather than using worst case meteorological assumptions. Concentration estimates produced by CAL3QHCR are lower because calm periods, which tend to have the highest concentrations, are not included in multi hour averages (effectively tossing out the peak concentrations). Data requirement for CALINE4, CAL3QHC and AERMOD is given in Table 2.1.

Table 2.1: Data Requirements for CALINE4, CAL3QHC and AERMOD

	CALINE4	CAL3QHC	AERMOD
Vehicle-Related Data			
Traffic Volume	√	√	√
Emission Factor	√	√	√
Average Total Signal Cycle Length		■	
Average Red Total Signal Cycle Length		■	
Clearance Lost Time		■	
Approach Volume on the Queue Link		■	
Idle Emission Factor		■	
Saturation Flow Rate		■	
Arrival Rate		■	
Meteorological Data			
Wind Speed	√	√	√
Wind Direction	√	√	√
Wind Direction Variation	√	▲	
Dry Bulb Temperature	√	√	√
Wet Bulb Temperature			▲
Dew-Point Temperature			▲
Atmospheric Stability Class	√	√	
Surface Roughness	√	√	√
Midday Albedo			√
Daytime Bowen Ratio			√
Total/Opaque Sky Cover			√
Sky Cover at layer 1,2,3,4			▲
Relative Humidity			▲
Precipitation Amount			▲
Precipitation Type			▲
Horizontal Visibility			▲
Cloud Type			▲
Sea Level Pressure			▲
Station Pressure			▲
Upper Air Sounding			√
Other Data			
Source Height	√	√	√
Mixing Zone Width	√	√	√
Link Geometry	√	√	√
Receptor Coordinates	√	√	√
Settling Velocity	√	√	
Deposition Velocity	√	√	
Longitude and Latitude			√

Where: √ = required input; ▲ = optional input; ■ = required for CAL3QHC's queue algorithm.

2.7 Validation of the Model

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 modeling. A fundamental requirement for the use of models in policy is that their predictions be credible. 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 pollution levels due to rapid industrialization and urbanization are now causes of major concern in industrializing countries. Air pollution threatens the human health and the gain in economic growth of any country and planning of air pollution control strategies is therefore essential in order to minimize the harmful effects of the emissions. The United States Clean Air Act of 1970 and its amendments have established National Ambient Air Quality Standards to protect man and his total environment from damage by air pollutants (Maynard, 1984). The clean air act produced strong motivation for the application of mathematical models to air quality problems. The Clean Air Act Amendments (CAAA) of 1977 first required the Environmental Protection Agency (EPA) to use air quality simulation models. The EPA held its first conference on air quality modeling in December, 1977. The Air Pollution Control Association (APCA) presented a Critical Review on “Atmospheric Dispersion Modeling” at the 1979 Annual Meeting and subsequently published a critical review as an APCA Reprint Series (Volume 10) in March, 1980.

Air quality management policies are usually developed through a series of processes, which include air quality monitoring, emission inventory preparation and control strategies delineation, and long-term compliance monitoring. In order to delineate appropriate air quality management plans, quantification of emissions from different air pollution sources and their impact on ambient air quality becomes essential. Ambient air quality management in any industrial area is a prime concern in India. Literature abounds in studies on air quality modeling and the effect of industrial emissions on ambient air quality. Below is presented a selection of works that have dealt with the topic and also the main inferences that emerge from these studies both at national and global levels.

3.1 Global Scenario

One of the first challenges in the history of air pollution modeling was the understanding of the diffusion properties of plumes emitted from large industrial stacks. One of the early air pollutant plume dispersion equation was derived for point source and this equation did not include the effect of ground reflection of the pollutant plume (*Bosanquet and Pearson, 1936*). Afterwards, a

point source air pollutant plume dispersion equation was derived which included the assumption of Gaussian distribution for the vertical and crosswind dispersion of the plume and also addressed the effect of ground reflection of the plume (*Sutton, 1932*).

Experimental evidence showed that the vertical distribution of spreading particles from an elevated point is related to the standard deviation of the wind elevation angle at the point of release (*Hay and Pasquill, 1957*). *Hay and Pasquill (1959)* also presented a method for deriving the spread of pollutants from records of wind fluctuation. *Pasquill (1961)* has further proposed a method for estimating diffusion when detailed wind data are not available. This method expresses the height and angular spread of a diffusing plume in terms of more commonly observed weather parameters. Suggested curves of height and angular spread as a function of distance downwind were given for several "stability" classes. The use and application of the Gaussian plume model spread over the whole globe and became a standard technique in every industrial country to calculate the stack height required for permits, (*Beryland, 1975*). Gradually, the importance of the mixing height was realized and its major influence on the magnitude of ground level concentrations (*Holzworth, 1967, Deardorff et al., 1975*). To include the effects of the mixing height, multiple reflections terms were added to the Gaussian Plume model (*Yamartino, 1977*).

The Gaussian plume model application also extends to line and area-sources. Line source dispersion has been studied since 1960s, when the regulatory framework in the United States began requiring quantitative analysis of the air pollution consequences of major roadway and airport projects. CALINE4 is an example of a dispersion model designed for road networks. This model extends the standard Gaussian plume formulation using a line source configuration and mixing zone that accounts for traffic-induced heat flux and mechanical turbulence (*Benson, 1989*). After 1970, it was realized that air pollution was not only a local phenomenon. It first became clear in Europe that the SO₂ and NO_x emissions from tall stacks could lead to acidification at large distances from the sources. So to tackle this simple Gaussian plume type modeling was not enough and two different modeling approaches were followed, Lagrangian modeling and Eulerian modeling. In Lagrangian modeling, an air parcel or puff is followed along a trajectory, and is assumed to keep its identity during its path. In Eulerian modeling, the area under investigation is divided into grid cells, both in vertical and horizontal directions.

Noll et al. (1978) compared three idealized line source dispersion models, i.e. USEPA's HIWAY and the original CALINE and CALINE 2 models that predicted CO concentrations near highways. A comparison of predicted and measured concentrations had shown that all these models overestimated concentrations for parallel wind conditions and underestimated for oblique and crosswind conditions. Also *Sistla et al. (1979)* highlighted the importance of mechanical turbulence generated by traffic flow in dispersing vehicular pollutants near the roadways. *Benson (1979)* developed a third version of the CALINE model (CALINE 3) that retained the basic Gaussian dispersion approach but used new vertical and horizontal dispersion curves modified to account for the effects of surface roughness, averaging time and vehicle-induced turbulence. The performance of CALINE 3 was evaluated by *Rao and Visalli (1981)*, who found it to be comparable with other line source models, i.e. HIWAY 1 and 2, AIRPOL 4 and CALINE 3. *Benson (1984)* represented a refinement and extension of CALINE 3 contained in CALINE 4. An option for modeling roadway intersections was also incorporated in it. The model uses a modified Gaussian plume approach similar to the one used in CALINE 3, but with new provisions for lateral plume spread and vehicle-induced thermal turbulence. *Benson et al. (1989)* also evaluated the performance of the CALINE 4 line source model for complex terrain applications based on a controlled field tracer study. They found the performance of the CALINE 4 model to be unsatisfactory and not as good as that for similar modeling situations in flat terrain. *Coe et al. (1998)* reformatted CALINE 4 in the form of a CL4 model, a graphical Windows-based user interface designed to ease data entry and increase the online help capabilities of CALINE 4.

Gronski (1988) carried out dual tracer field experiments to understand the influence of vehicle speed on the dispersion of exhaust gases by studying vehicle wakes. It was shown that the vertical diffusion of exhaust gases tended to be larger from vehicles driving with high speed than from those driving at lower speeds. *Eskridge et al. (1991)* carried out wind tunnel investigations and numerical modeling on modified ROADWAY model. The study revealed that the influence of traffic speed on the ambient pollutant concentrations was not significant during unstable and neutral conditions but could be significant under extreme stable conditions. *Clifford et al. (1995)* studied the mechanisms involved in the dispersion of pollutants around slow moving city traffic conditions in a low velocity wind tunnel. The tracer study indicated that the exhaust gases were

entrained in the wake of the vehicle from which they were emitted and were dispersed mainly by the passage of the following car.

Meng et al. (2000) discussed a new statistical framework for estimating CO impacts, with the intention of replicating the microscale modeling results achieved with CAL3QHCR. The results of the study showed that the proposed model can be easily and reliably used by traffic engineers to predict potential CO exceedances at the planning stages for transportation projects. *Hassid et al (2000)* used US EPA Gaussian models for developing environmental impact statements that focused on four different sectors: highway, quarries, airports, and tunnels. The main problems encountered are the uncertainties in the emission factors, the lack of accounting of complex terrain effects. Gaussian plume equations assume a homogeneous wind field so it is not recommended that they are used for far field modeling as the meteorology is expected to change over such large distances. *Zhou and Sperling (2001)* used the CAL3QHC model for determining pollutant concentrations at various intersections of Shanghai and noted that mixed traffic (bicycles and vehicles) and near road high rise buildings will cause CAL3QHC to poorly predict CO concentrations.

Moseholm et al. (1996) showed that CAL3QHC (for CO and PM) yielded unsatisfying results under conditions involving low wind speeds and nearby tall buildings. The study conducted by *Toro et al. (1998)* presented the potential dispersion modeling uses of archived National Oceanic and Atmosphere 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. *Simms et al.(1999)* considered the effects of building downwash on air pollution dispersion and the significance of short averaging time. *Dabberdt et al. (2000)* addressed modeling issues relating to accidental chemical release. *Koracin et al. (2000)* performed a comprehensive modeling study of PM-10 impact in Treasure Valley, Idaho using ISCST3 model.

EPA (2002) also conducted a peer review on AERMOD for single stack dispersion. The AERMOD consequence analysis was evaluated using two different land classifications (urban and rural), all three types of sources (point, volume and area) in three types of terrain (flat, simple and complex).

Caputo et al. (2003) observed that Gaussian models calculated non zero concentrations for the whole downwind domain and it should be limited to distances a few tens of kilometers from the source. *Indra et al. (2004)* also studied the different air pollution dispersion models and found that dispersion and emission of pollutants into the air is controlled by the prevailing meteorological conditions like wind profile, temperature profile and stability of the atmosphere. *Holmes et al. (2006)* showed that AERMOD aims at modeling short-range (up to 50 km) dispersion from a variety of polluting sources (e.g. point, area, and volume sources) using a number of model configurations.

Gramotnev et al. (2003) used a modified version of CALINE4 to estimate motor vehicle emission factors of fine and ultrafine particles near a busy road in the Brisbane area in Australia. Employing the resulting emission factors, they found that the CALINE4 model results matched the observed rate of dispersion with distance from the road well. *Broderick et al. (2005)* examined CALINE4 performance of modeling transportation related CO for a free flowing motorway and a periodically congested roundabout in Ireland and concluded that CALINE4 functioned well under stable atmospheric conditions but performed poorly under low wind conditions. However, CAL3QHC was shown to perform well generally in open areas with moderate traffic volumes (*Abdul-Wahab, 2004*).

Levitin et al. (2005) evaluated and inter-compared two atmospheric dispersion models (CALINE4 and version 3 CAR-FMI) against the results of a measurement campaign conducted near a major road at Elimaki in southern Finland from September,15 to October,30 1995. The agreement of measured and predicted datasets were good for both models, as measured using various statistical parameters. They also analyzed the difference between the model predictions and measured data in terms of the wind speed and direction. The performance of both models in most cases deteriorated as the wind speed decreased, and as the wind direction approached a direction parallel to the road.

Koo et al., (2005) reviewed CALINE3 and CALINE4 dispersion models and vehicle emission factors in evaluating the effect of pollutants emitted by the vehicles in highway on nearby area in Korea. The comparisons of predicted concentrations by the models with the measurements in flat, fill and bridge road types showed that CO and PM10 were in good agreements with experiments and the differences between CALINE 3 and 4 models are negligible. The model concentrations of NO₂ by CALINE 4 were also in good agreement with the measurement but

those by CALINE 3 were over-predicted. The discrepancies in CALINE 3 model were due to rapid decay reaction of NO₂ near the highway, which was not included in CALINE 3 model. These results lead to the conclusion that CALINE4 model is proper in road environmental impact assessment near the highway in flat, fill and bridge road types.

Wang et al. (2006) used developed local general finite line source model (GFLSM) to investigate the traffic induced gaseous and particle emissions dispersion characteristics from the typical urban roadside sites in Hong Kong. A high level of agreement found between the measured and calculated CO and PM_{2.5} data.

Schewe et al. (2003) Compared modeled pollutant concentrations predicted by AERMOD with observed concentration and reported that 3-hr 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. Also *Stein et al. (2007)* stated that AERMOD model has the capacity to employ hourly sequential preprocessed meteorological data to estimate concentrations of pollutants at receptor locations at different time scales ranging from 1 h to 12 months. AERMOD has recently been added to the list of recommended models for regulatory applications (*CPCB, 2008*). *Silverman et al. (2007)* compares the ISCST3 and AERMOD dispersion models as well as their enhanced versions that incorporate the Plume Rise Model Enhancement (PRIME) algorithm for human health risk assessment. The result shows that switch from ISC to AERMOD and the incorporation of the PRIME algorithm tend to generate lower concentration estimates at the point of maximum ground level concentration, however the magnitude of difference varies from insignificant to significant depending on the type of the sources and the site specific conditions.

AERMOD can be used for predicting the concentrations of various pollutants emitted by point, line and area sources. This model is typically used for large areas (*Faulkner et al., 2007*) or stationary sources (*Orloff et al., 2006*). *Zhang et al., (2008)* used AERMOD to estimate PM₁₀ concentrations in the urban area of Hangzhou, China and found that AERMOD underestimated concentrations; the authors noted that model performance may have been related to lack of consideration of construction and secondary particle.

Taseiko et al., (2008) used a semi-empirical mathematical model, Urban Street Model (USM) to efficiently estimate the dispersion of vehicular air pollution in the city of Krasnoyarsk (in Eastern Siberia). The USM-predicted numerical results were compared with field measurements and with

results obtained from other frequently used models, CALINE-4 and OSPM. USM consistently yielded the best results. OSPM usually overestimated pollutant concentration values. CALINE-4 consistently underestimated these values. For OSPM, the maximum differences were 160% and for CALINE-4 about 400%.

Zou et al. (2010) estimated that urban/rural dispersion coefficients have limited influence on the AERMOD performance. They also used AERMOD as a modeling tool for population exposure assessment at different time scales. They evaluated the performance of AERMOD in estimating SO₂ concentrations in Dallas and Ellis counties in Texas at different time scales. Results suggested that SO₂ concentrations simulated by AERMOD at the 8 h, daily, monthly, and annual intervals match their respective observed concentrations much better compared with the simulated 1 and 3h SO₂ concentrations. In addition, AERMOD performed better in simulating SO₂ concentrations when combined point and mobile emission sources are used as model inputs rather than using them alone and also showed better performance at the monthly scale in simulating the high end of the spectrum of SO₂.

Mihaiella et al. (2010), also predicted pollution through atmospheric dispersion modeling and found that the exposure to ambient air pollution is associated with a series of adverse health effects. Their aim was to quantify the contribution of various pollution sources (incinerator and thermal power station), to the local air pollution from an airport area.

William et al. (2012) determine 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. 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 and surface roughness. 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 demonstrate AERMOD's sensitivity to small changes in wind speed and surface roughness. Sensitivity analysis was also done for ISCST3 and AERMOD in a complex terrain and flat terrain scenario (*Trade and Westbrook (2003)*, *Morrison (1998)*). AERMOD seems to perform better in complex terrain than ISCST3.

Ding (2012) applied AERMOD model to stimulate the pollutant concentration at different heights in the Belgium District, China. The concentration of SO₂ and NO₂ was relatively higher in the upper air of the district Belium.

Tartakovsky et al. (2013) also calculated the concentrations of particulate emissions from a quarry located in hilly terrain by AERMOD and CALPUFF atmospheric dispersion models. Due to severe uncertainties in the input parameters model sensitivity was studied. Model results were compared among themselves, and to measured total suspended particulate (TSP). AERMOD predictions were in a better agreement with the measurements than those obtained by CALPUFF. *Bhatt et al. (2013)* used CALROADS line source dispersion model to determine the safe roadway buffer width to protect human health from NO₂ exposure in Great Southwest Parkway in Grand Prairie, Texas. It was determined that, traffic volumes on the roadway could increase by a factor of 10 and still the 20 foot buffer width would still be sufficient to protect human health from NO₂ exposure.

Heist et al. (2013) studied inter-comparison of four steady-state Gaussian dispersion models (AERMOD, run with both the area-source and volume-source options to represent roadways, CALINE, versions 3 and 4, ADMS and RLINE) to capture near-road pollutant dispersion. All four models showed an ability to estimate the majority of downwind concentrations within a factor of two of the observations. RLINE, AERMOD-V, and ADMS, also have the capability to predict concentrations upwind of the roadway that result from low-speed meandering of the plume. Generally, RLINE, ADMS, and AERMOD (both source types) had overall performance statistics that were broadly similar, while CALINE 3 and 4 both produced a larger degree of scatter in their concentration estimates. The models performed best for near-neutral conditions in both tracer studies, but had mixed results under convective and stable conditions.

Dongsheng et al. (2015) evaluates the performances of CAL3QHC and CALINE4 in predictions of PM_{2.5} and CO at 5-min scale. Results show that CAL3QHC generally performs well for 5-min predictions of both PM_{2.5} and CO compared with CALINE4. Besides, both models perform better at off-peak than peak periods, which can be attributed to the fluctuation of high traffic volumes as well as the more complex mechanical turbulence induced by passing vehicles in peaks. Furthermore, performances of both models are more related to wind speed particularly when predicting CO concentrations. When wind speed is less than 1m/s, both models will have better performances. The outputs of these findings demonstrate the potential of both models to be applied to forecast the real-time trends of air pollution as well as to capture the extreme values due to varied scenarios at road intersections.

Although the model has not been widely used in predicting near road pollutant concentrations, EPA recommends AERMOD to evaluate near-road concentrations (USEPA, Accessed July 10, 2008) and thus it is included in this study.

3.2 National Scenario

The problem of air pollution has assumed serious proportions in some of the major metropolitan cities of India and vehicular emissions have been identified as one of the major contributors responsible for the deteriorating air quality in these urban centers (*CPCB, 1999*). In India, various Gaussian-based line source models like CALINE 3 and 4, GM and HIWAY 4 are routinely used to predict the impact of vehicular pollution along roads/highways. Most of these predictions or estimations are carried out as part of environmental impact assessment (EIA) studies. The EIA notification of 4th May 1994 had made it mandatory for all new and existing highway/road projects to carry out EIA studies. *Luhar and Patil (1989)* developed a simple finite line source model (GFLSM) based on the Gaussian diffusion equation so that it could be used for any orientation of wind direction with the roadway and also it did not have the infinite line source constraints of the GM model. The GFLSM was also evaluated and compared with other line source by using observed CO levels near the two traffic junctions in Mumbai and data generated in NYS experiments. *Sivacoumar and Thanasekaran (1999)* also used the GFLSM to predict the CO concentrations near major highway in Chennai. *Khare and Sharma (1999)* modified General Finite Line Source Model (GFLSM) to Delhi Finite Line Source Model (DFLSM) considering the existing traffic and meteorological conditions in Delhi and compare predicted CO concentrations with the measured values obtained from the experiments conducted by Central Pollution Control Board (CPCB). The predicted and observed CO concentration data reveals that the DFLSM model works more accurately in comparison to the GFLSM.

Sivacoumar et al. (2001) estimated the impact of NO_x emissions resulting from various pollution sources, viz. industries, vehicles and domestic in Jamshedpur using were ISCST and AERMOD. 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%. Dispersion model ISCST-3 is used to study the impact of an industrial complex and dispersion of pollutants on air quality and model-predicted concentrations were in good agreement with observed values and the model performance was found to be satisfactory (*Rama Krishna et al.,(2004), Reddy et al., (2005)*).

Kesarkar et al. (2007) used AERMOD to estimate PM₁₀ concentrations over the city Puna in India and found that the model generally underestimated PM₁₀ concentrations except for residential areas. AERMOD model is validated by comparing the predicted levels with the estimated levels of PM₁₀ in Madurai and concentration was found below the Indian air quality standards by *Bhaskar et al. (2008)*.

Also mathematical models i.e. FDM, ISCST3 and AERMOD were employed for prediction of dust emission from stone crushers on the surrounding areas at Trisoolam in Chennai by *Sivacoumar et al. (2009)*. Both ambient dust concentration and occupational exposure level exceeded Indian National Standards at most of the locations. *Bhati et al. (2009)* estimated that 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 AERMOD in Delhi. Mortality assessment revealed that 20% decrease in vehicular emissions leads to five times greater reduction in the mortality count as compared to a major shift coal to natural gas sources in power production sector. *Goyal et al. (2010)* assess the impact of diesel vehicles on NO_x and PM emissions at various locations in Delhi using two CALINE4 and the Indian Institute of Technology Line Source(IITLS). The models offer comparable results but both under predicting the observed values with the IITLS model predictions being slightly better which may be due to either the inclusion of the treatment of low wind which are neglected in Caline-4 or the emission inventory of Caline-4, requires detailed data of road links and traffic in each grid, which is not always available whereas, the source inventory of IITLS is based on readily available traffic data. *Gupta et al. (2011)* predicted average hourly and 8 hourly CO using three different models viz. CALINE 4, CAL3QHC and CAL3QHCR in New Delhi for three peak hours (morning, afternoon and evening peak hour) of winter season. CAL3QHCR showed good predicting capability in comparison to CALINE4 and CAL3QHC. Predicted CO concentration lies within the prescribed permissible limits. *Banerjee et al. (2011)* performed the source-contribution assessment of ambient NO₂ concentration at Pantnagar, India through simulation of Gaussian Finite Line Source Model (GFLSM) and ISCST-3. Models simulation indicated that contribution of NO₂ from industrial and vehicular source was in a range of 45–70% and 9–39%, respectively.

Mohan et al. (2011) evaluated AERMOD (07026) and ADMS-Urban (2.2) for Delhi. ADMS-Urban shows greater tendency towards under prediction when compared to AERMOD and

AERMOD requires more input meteorological data as compared to ADMS-Urban. Overall, both the models have comparable performance and the differences between estimated concentrations are mainly due to processing of the meteorological data. Specifically the influence of boundary layer estimations on the model results were observed that could explain most of the differences amongst the two models. *Mishra and Srivastava (2012)* studied the CO level predicted by CALROAD view model in the surrounding areas due to upcoming of an international airport in Navi Mumbai. CO concentration was monitored at 10 locations in Navi Mumbai around the airport within the radius of 10 km from ARP (Airport Reference Point) and air quality status was evaluated at all locations. Predictions for CO were done separately for vehicular traffic and airport traffic. Results showed that the increase in vehicular traffic due to airport operation will have no considerable impact on the air quality of the study area.

Konar and Chakrabarty (2012) applied CALINE4 line source dispersion tool to model NOx with and without canyon options activated near Jadavpur University, Kolkata. Model exhibits better correlation for 'with canyon' option than 'without canyon' against actually measured concentrations of NOx, which is indeed more realistic to reflect actually prevailing condition, as the study site is situated in a street canyon.

Dubey et al. (2013) also used CALINE4 model to predict CO concentration, which is chiefly emitted from vehicular source, at various traffic junction in Dhanbad city. Model is found more applicable for one hour modeling of CO. *Dhyani et al. (2013)* evaluated the performance of CALINE 4 model in hilly terrain for Indian traffic and meteorological conditions. CALINE 4 model predictions have been compared between flat and hilly terrains along two road corridors in Solan District in the state of Himachal Pradesh (India). The model performed satisfactorily in the flat terrain. However, model fell short in explaining the complexity of terrain and performed unsatisfactorily in hilly terrain conditions. *Sharma et al. (2013)* evaluated the performance of CALINE4 in predicting CO concentration using two different emission factors: CPCB and Automotive Research Association of India (ARAI) along the urban highway corridor passing through Delhi. The concentration was found to be 12% higher in ARAI emission factor in comparison to CPCB. Overall model shows satisfactory performance.

Dhyani et al. (2014) assess the CO prediction along urban highway corridor (without street canyon effect) using CALINE 4 air dispersion model. Model performance found satisfactory on

the basis of statistical descriptors under various Indian meteorological condition and heterogeneous traffic conditions.

3.3 Research Gaps

Air quality in urban areas can be determined either through monitoring or by prediction models. Air pollution models are routinely used in environmental impact assessments, risk analysis and emergency planning, and source apportionment studies. From the detailed literature review mentioned above, it is evident that few reports highlights the air quality impacts near transportation facility in India, but still study is incomplete and partial in comparison to global scenario.

- Traffic Emission inventories were reported for rare areas leads to difficulty in compiling the input data for modeling.
- CALINE4 is strictly line source based model and AERMOD is more versatile in nature. Performance evaluations of outcomes from different steady state based models are rarely used for air quality assessment in India.
- AERMOD is a line, point, area and volume source model and is mainly used for stationary sources and rarely used in predicting near road pollutant concentrations, EPA recommends AERMOD to evaluate near-road concentrations (*USEPA, Accessed July 10, 2008*) and thus it is included in this study.
- Further, no detailed study of the prediction of ground level concentration of various pollutants emitted from vehicular source at sensitive receptors using steady state dispersion models has been published in Patiala city. This will help in providing database to prevent and minimize the deterioration of air quality in the study area.
- Recently, some effort has also been made in India to apply statistical models to predict pollutant concentrations from observed meteorological and traffic parameters. However, owing to a lack of comprehensive, long-term and reliable data on pollution, traffic and meteorological parameters, a statistical modeling exercise has been carried out only for a few major metros, whereas these data to a certain extent are available with various government agencies and R&D organizations.

3.4 Objectives of the present study

Keeping in view the research gaps observed in the literature, the present study aims at the following key objectives:

1. To prepare an emission inventory for traffic data on major traffic intersection.
2. Use of AERMOD and CALINE4 dispersion modeling techniques for predicting the ground level concentration of pollutants at different receptors and its comparison.
3. Performance evaluation of the models 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 CALINE4) and procedures used for vehicle monitoring and analysis of pollutant concentrations.

4.1 Chemicals used for NO_x Analysis

Chemicals used for the analysis are Sodium hydroxide assay of 98%, Sodium arsenite assay of 98-102 %, Sulphanilamide assay of 99% with melting point 165 to 167⁰C, N-(1-Naphthyl)-ethylenediamine Di-hydrochloride (NEDA) assay of 99% , Hydrogen peroxide assay of 29-32%, Phosphoric acid assay of 85%, and Sodium nitrite assay of 98% . All the chemicals used were acquired from Loba Chemie Company, India.

4.2 Instrumentation

4.2.1 High Volume Sampler with gaseous attachment

High Volume Sampler is 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 this sampler, airborne 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 was placed away from the buildings in open space mainly above ground level to avoid building downwash effect because it leads to dry deposition of particulates and under prediction in the measured concentration. The instrument measured the volume of air sampled, while the amount of particulates collected was 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. It consists of a set of 4 impingers (bubblers), carried in an ice tray. The impingers can be operated either in series or parallel according to the requirement. The impingers was filled with up to 30 ml of the absorbing reagent. Gaseous sampling requires only 0.2 to 2 L/min of airflow through individual impingers. The impingers have a common outlet for the air after it passes through the reacting reagent. The outlet was connected to a tapping on the suction side of the blower for drawing in the air. The flow through

the impingers was regulated by means of individual needle valves, for each of the 4 impingers, and one common outlet. The airflow rate was adjusted/ measured with a rotameter provided with the attachment. The air passed through suitable reagents that would absorb specific gases where gaseous pollutants like SO₂, NO₂ etc. were analyzed subsequently by simple wet chemistry method to determine the concentration of specific pollutant.



Figure 4.1: High Volume Sampler APM 415

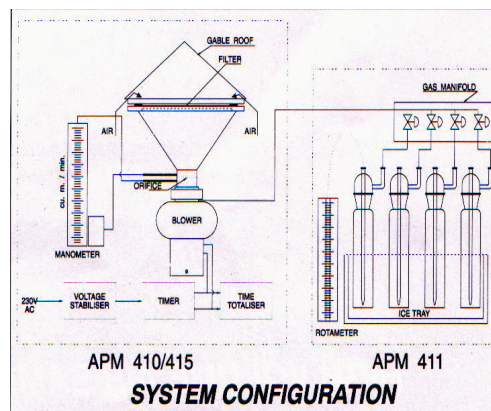


Figure 4.2: System configuration of gaseous extension with HVS

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 360⁰; air temperature: -20 to +70⁰; air humidity: 20 to 100% and rainfall: 6.5cm measurement period. 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. Weather monitoring station was installed at rooftop (D block) of Thapar University (30⁰35'39''N, 76⁰37'07''E) where there is no obstruction in path of wind so that correct data can be collected.



Figure 4.3 Weather Monitoring Station

4.2.3 UV-VIS Spectrophotometer

The spectrum was taken with UV- VIS Spectrophotometer (Hitachi V-500 UV/VIS (Japan) double- beam spectrophotometer). The scan speed is 200nm/min with a step of 1.0 nm. Wavelength resolution is 0.1nm. Spectrophotometer is having both Tungsten and Deuterium lamp at operating temperature of 0-40⁰C.

4.2.4 Models Used

For the modeling of dispersion of vehicular emitted pollutant, AERMOD View version 8.8.9 gaussian plume dispersion model and CALINE version4 under CALROADS view version 6.2.6 traffic air dispersion model released by Lakes Environment was used.

4.3 Methodology

The study was carried out in following steps which are:

- Selection of sampling site
- Meteorological monitoring
- Source Emission Inventory
- Use of AERMOD and CALINE4 for modeling
- Air quality monitoring and Analysis
- Validation of Models

4.3.1 Selection of sampling site

The study area was chosen to be Patiala city. Although, there are not many industries in the surrounding areas, some of the industries which could have significant impact on the local environment include Federal Moughal Goetze India Ltd. and Milkfood on Rajpura Road, Verka Milk Plant, DMW and Focal Point on Sirhind Road, Maltex Malsters on Nabha Road. Almost all the industries have installed suitable pollution control systems and there is less impact of industries on the local environment. The main sources of air pollution in Patiala City are burning of LPG gas/kerosene oil in households/restaurants, vehicular movement within and around the city, operation of DG Sets in case of failure of electrical power, stubble burning etc. The air pollution due to the burning of LPG gas/kerosene oil is minimal. In traffic and transportation; roads, railway line & station, truck terminus, bus terminus, bridges and flyovers cover 10.09 % of the total developed area and the major share i.e. 9.20% of total developed area is covered under roads (Prepared by Punjab Remote Sensing Centre, Ludhiana). There is no organized parking space for taxis and auto, rickshaws. Although truck terminal of 40 acres has been planned on Patiala – Rajpura road, numerous booking agencies are running within the city.

Recent surveys of traffic indicate that most of the road network is not congested. Only four roads namely one from Fountain chowk to Leela Bhawan, second from Thapar University to Gurudwara Dukhniwaran Sahib, third from Fountain Chowk to Mohindra college (Lower Mall) and fourth from Gurudwara Dukhniwaran Sahib to Bus stand have Volume/Capacity (V/C) ratio well in excess of 1 (Master Plan L.P.A Patiala, (Document of Government of Punjab 2011)). There is acute shortage of parking particularly in the traditional bazaars, planned commercial areas and in private institutions which results in parking spill over on important roads thus causing congestion of traffic. Due to increase in population growth load on vehicular traffic increases which may lead to increase in vehicular air pollution.

In the study area, 17 roads (links) covering major areas of the city were studied for traffic monitoring in order to know the vehicular composition and volume of the road to calculate the combined contribution of both diesel and petrol driven vehicles in the air quality of the city.



Figure 4.4: Study area of Patiala city for traffic monitoring

Characteristics of major road under study of Patiala city is given in Table 4.1 including length , width and divided/undivided road.

Table 4.1 Description of the study area (Source D.T.P Office Patiala)

S.No.	Link_ID	Name of the Road	Length (Km)	Width (m)	Divided/Undivided
1	LINE1	Fountain Chowk -Bus Stand	1.54	10	Divided
2	LINE2	Fountain Chowk -Leela Bhavan	0.7	13.5	Divided
3	LINE3	Fountain Chowk -Lower Mall	2.25	10	Undivided
4	LINE4	Fountain Chowk -Thikriwala Chowk	0.7	10	Divided
5	LINE5	Leela Bhawan Chowk – Nabha Road (Bhupindra Road)	2.1	7.32	Divided
6	LINE6	Leela Bhawan Chowk - Gurdwara Sahib (Rajbaha Road)	1.46	13.5	Divided
7	LINE7	Leela Bhawan Chowk - Baradari Garden	1.1	6.5	Undivided
8	LINE8	Thapar University - Bhadson Road	0.8	6.71	Divided
9	LINE9	Thapar University - Nabha Road	2.6	6.9	Divided
10	LINE10	Thapar University - Bhupindra Road	0.7	7.32	Divided
11	LINE11	Thapar University - Gurdwara	2.25	7.3	Divided

		Sahib			
12	LINE12	Gurudwara Sahib Chowk- Sirhind Road upto M.C. Limit	4.4	7.32	Divided
13	LINE13	Gurudwara Sahib Chowk- Nabha Road (Passey Road)	2	10	Undivided
14	LINE14	Gurudwara Sahib Chowk- Bus Stand Road	0.9	6.71	Divided
15	LINE15	Bus Stand Chowk- Rajpura Road	4.8	8.23	Divided
16	LINE16	Bus Stand Chowk- Gurbax Colony	2.1	6	Divided
17	LINE17	Bus Stand Chowk- Dukhnavaran Sahib (Beneath Flyover)	1.21	7	Undivided

4.3.2 Meteorological Monitoring

The meteorological factors affect a range of atmospheric characteristics and dispersal of pollutants. Meteorological data for use in air quality dispersion modeling consist of physical parameters that are measured directly by instrumentation, and include ambient air temperature, wind direction, wind speed, cloud cover, ceiling height, relative humidity, atmospheric pressure, visibility, solar radiation and precipitation amount. 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. Daily mean hourly meteorological data was collected from January-April, 2015 using Watch-Dog Weather monitoring station installed at rooftop (D Block) of Thapar University (30°35'39"N, 76°37'07"E) Patiala. Additional data was collected from Indian Meteorological Department (IMD) station ID-42101, Patiala. The data was valid to nearly 30 kms area. Data was then compiled in an excel file for further processing in AERMET view.

4.3.3 Source Emission Inventory

The dispersion of pollutants along with meteorological conditions also depends upon the source characteristics (traffic composition, length of the road, width of the road, emission rate, type of vehicle whether petrol or diesel driven, volume of the road) included in the emission inventory. For 17 major roads (links) of the city traffic composition, length of the road, width of the road, volume of the road and other relevant data was collected from Master Plan Patiala (2010-2031) report by Punjab Urban and Development Authority (PUDA 2011). Emission factor for Indian vehicles was collected from Emission Factor development for Indian Vehicles as a part of

Ambient Air Quality Monitoring and Emission Source Apportionment Studies (CPCB/ARAI Pune 2008).

Traffic monitoring (12 hours) for the below mentioned links were carried in the months of January-April, 2015 fortnightly. Continuous traffic count was performed from 8:00 AM to 8:00 PM on hourly basis. Traffic volume comprises of heavy commercial vehicles (Bus/Trucks), light commercial vehicles, three wheelers (M3W), cars with different capacity and different fuel type and two wheelers (M2W).

1. Thapar University to Dukhnivaran Gurdwara Sahib
2. Thapar University to Bhadson Road
3. Thapar University to Bhupindra Road
4. Thapar Univeristy to Nabha Road

Emission rate was calculated from emission factors, link and vehicular description as per the model requirement which was further used by AERMOD and CALINE4.

The estimation of transport- related emissions was done based on the equation:

$$E = e * a,$$

Where E is the amount of emission, e is the emission factor per unit of activity, and 'a' is the amount of transport activity. This equation was applied for each vehicle category, since the emission factors and the activity are different.

The emission factor, e, is usually expressed g/km and primarily related to driving conditions and vehicle type. The activity ,a, is a product of the number of vehicles for each of the categories and travelled distance by vehicle over the time unity, in km.

Emission rate for CALINE 4 was calculated by :

$$\text{Emission rate (g/mile-vehicle)} = \{ \sum [\text{Emission factor (g/km-vehicle)} * (\text{Number of vehicles/hour})] / (\text{Total number of vehicles} * 0.621) \}$$

Emission rate for AERMOD was calculated by:

$$\text{Emission rate (g/sec)} = \{ \sum [\text{emission factor (g/km-vehicle)} * (\text{No of vehicles/hour})] * \text{length of the link in km} \} / 3600$$

4.3.4 Use of AERMOD and CALINE4 for Modeling

In order to conduct a refined air dispersion modeling project using the U.S. EPA AERMOD and CALINE4 air quality dispersion model, the meteorological data of the area was processed in case of AERMOD using the U.S EPA AERMET program.

AERMET

AERMET is the meteorological preprocessor for AERMOD. There are three stages to processing the data. The first stage extracts meteorological data from archive data files and processes the data through various quality assessment checks. The second stage merges all data available for 24-h periods and stores these data together in a single file. The third stage reads the merged meteorological data and estimates the necessary boundary layer parameters for use by 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. The necessary data collected for AERMET include Wind direction (degree), Wind Speed (m/s), Dry bulb temperature ($^{\circ}\text{C}$), Relative humidity (%), Atmospheric pressure (mm-Hg), Rainfall (cm), Solar radiation (wat/m^2) and opaque cloud cover (okta).

AERMOD

A typical AERMOD interface uses the five pathways to develop an input file. These pathways are Control pathway, Source pathway, Receptor pathway, Meteorological Pathway and Output pathway.

Control pathway: Control pathway is a collective term used to specify the overall job control options including titles, dispersion options, type of pollutant to be modeled, terrain option and pollution averaging time option. For our study, the type of pollutant (CO, NO₂ and PM) and averaging time values for output concentrations of 1h and periodically was selected with rural dispersion coefficient

Source pathway: Source pathway feature enables the handling of multiple sources, including point, line, area and volume sources. Several source groups may be specified in a single run, with the source contributions combined for each group. It also has various features like building downwash, urban sources, and hourly emission file. In this study, models uses line source as

source parameters and the line source characteristics (emission rate, width of the link, starting and ending coordinates of the link) data were added.

Receptor pathway: Receptors are the people or objects negatively affected from the pollution. Receptor grids can be created automatically or manually using Cartesian or polar coordinates. Concentrations can be calculated for all the terrain elevations and for receptors above ground elevation (flagpole receptors). Here, Uniform Cartesian grid and 5 discrete Cartesian receptors i.e. Thapar University, Gurdwara Dukhnivaran Sahib, Gopals Sweets, Columbia Asia Hospital and Kali Mata Mandir were located in base map to get the pollutant concentrations on the sensitive sites of the study area.

Meteorology pathway: In this, the model uses a file of surface boundary layer parameters and a file of profile variables including wind speed, wind direction and turbulence parameters. The output files of AERMET surface and profile files (.sfc and .pfl) were taken directly as meteorological input from AERMET. It specifies the meteorological data file and information about the meteorological stations.

Output pathway: It specifies the output options for a particular run such as contour plots files. Output pathway of these model allows producing the following types of output data: summaries of high values by receptor for each averaging period and source group combination, summaries of overall maximum values for each averaging period and source group combination and concurrent value tables summarized by receptor for each averaging period and source group combination for each day of data processed

CALINE4

A typical CALINE4 interface uses the five pathways to develop an input file. These pathways are Job pathway, Meteorological pathway, Output pathway, Link pathway and Receptor pathway.

Job pathway: In this option user define project information such as type of pollutant to be modeled, model type run (Standard (1 h average), Worst case wind angle (1 h average), Multi-Run (8 h average), Mutli-run/Worst case hybrid (8 h average)), surface roughness length, settling and deposition velocity of the pollutant. In our study, 1 h averaging option is considered for >200 surface roughness length with zero settling and deposition velocity.

Meteorological pathway: Model allows defining 1 h or 8 h of meteorological data, depending on the run type selected in the job option. Inputs require in this option are wind speed (min 0.5

m/sec), wind direction, atmospheric stability class, mixing height, wind direction standard deviation, pollutant background concentration and ambient temperature. All the meteorological pathway was specified as per meteorological data collected bypassing the mixing height effect.

Output pathway: Under the Output options conventions for links and receptors IDs were specified.

Link pathway: A link is defined as a segment of roadway having a constant width, height, traffic volume, and vehicle emission factor. The location of a link is given by the coordinates of the two endpoint of a link centerline. In this one can specify single link and Group links. In this type of link, link height, mixing zone width (roadway width + 6 m), link starting and ending coordinates are defined in link geometry tab. Under link activity tab, hourly traffic volume and composite emission factor (g/v-mile) are defined for each link. In this modeling can be done with and without canyon option. Link description was specified on the basis of source inventory.

Receptor pathway: Receptors are defined as where pollutant concentrations caused by mobile sources are to be calculated by the model. Discrete receptors are usually used when there is a need to identify the pollutant concentration at specific points. Receptors are usually placed at a height of 1.8 m above ground (breathing height). Here, Uniform Cartesian grid and 5 discrete Cartesian receptors i.e. Thapar University, Gurdwara Dukhnivaran Sahib, Gopals Sweets, Columbia Asia Hospital and Kali Mata Mandir were located in base map to get the pollutant concentrations on the sensitive sites of the study area.

After run of model contours will be generated and output file is produced.

4.3.5 Air quality monitoring and Analysis

Air quality monitoring for NO₂ and SPM was carried out a periodic intervals at Thapar University, Patiala for 24 h duration using High volume Sampler (HVS) along with impinger train with suitable absorbing solution.

For the analysis of NO₂ and SPM, Indian Standard methods IS 5182 (Part 6) and IS 5182 (Part 4) :1999 were followed respectively.

Background concentration of carbon monoxide and ozone were obtained from Indian Institute of Tropical Meteorology, Pune continuous Ambient Air Quality Monitoring Station at Thapar University.

4.3.6 Validation of AERMOD and CALINE4 Model

Background sources are considered as an essential element of the total air quality analysis when examining source impacts. Background air quality consists of the pollutant concentration due to the following: natural sources, nearby sources other than the one currently under review and unidentified sources. These monitored background concentration at Thapar University were than validated against observed ground level concentration at Thapar University for 1 h average concentration of CO, NO₂ and SPM.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter incorporates the input data such as, meteorological source, source emission inventory and land use to generate wind rose and the isopleths through air quality modeling for estimating concentrations of pollutants at receptor point and overall maximum pollutant GLC. Meteorological and source emission inventory was prepared to be used in American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD) and California Line Source Model version 4 (CALINE 4) software which were employed for modeling of emissions from line source. AERMOD and CALINE4 models were used in order to estimate concentrations of line source emitted pollutants, namely CO, NO₂ and SPM for one hour averaging period. In order to compare the accuracy of the above models for line source, both the models were validated and evaluated for a daily mean concentration from both models against the observed GLC for a given receptor point. As a result, different maximum GLC values, different maximum GLC locations and a different correlation graphs were obtained as a result of modeling executions, thus showing the model performance.

5.1 Source emission inventory

At present, road traffic constitutes one of the principal sources of air pollution in urban areas and it is responsible for a significant portion of anthropogenic emissions. To develop a consistent approach for analyzing traffic-induced environmental pressure, a precise quantification of pollutant amount emitted by vehicles to the atmosphere is essential.

For the current study, 17 major roads within Patiala city were identified. Table 5.1 shows the hourly monitoring of 17 links with number of travelling vehicles of different category (*Master Plan L.P.A Patiala. (Document of Government of Punjab 2011)*) and Table 5.2 shows the hourly traffic monitoring of LINK 8,9,10 and 11 which were self monitored fortnightly during the month of January-April,2015. Emission factor for different categories is given below in Table 5.3.

Table 5.1: Hourly Monitoring of 17 major links within Patiala City

Link_ID	No. of Vehicles									Total
	Bus/ Truck (>6000cc)	Car (Petrol)			Car(Diesel)		SUV <3000cc	3W	Scooter/ Motor cycle	
		<1000cc	1000- 1400cc	>1400cc	<1600cc	1600- 2400cc				
LINE1	301	523	419	98	450	24	329	81	1688	3913
LINE2	586	309	247	57	283	14	194	48	942	2680
LINE3	46	315	251	58	288	14	197	48	965	2182
LINE4	697	581	464	108	532	26	365	90	2183	5046
LINE5	151	396	316	74	362	18	248	61	1704	3330
LINE6	954	422	334	78	386	19	265	65	1907	4430
LINE7	3	52	41	10	47	2	32	8	775	970
LINE8	150	133	106	25	122	6	83	20	468	1113
LINE9	56	77	62	15	71	3	48	12	335	679
LINE10	44	102	81	19	93	5	64	16	734	1158
LINE11	262	124	99	23	114	6	78	19	732	1457
LINE12	161	114	91	21	104	5	71	18	364	949
LINE13	107	160	128	30	146	7	100	25	753	1456
LINE14	172	191	153	36	175	9	120	30	781	1667
LINE15	727	515	412	96	472	23	323	79	1420	4067
LINE16	7	23	19	4	22	2	15	4	1478	1574
LINE17	941	450	360	84	412	21	282	69	1375	3994

Table 5.2: Hourly Traffic monitoring of self monitored links

Link_ID	No. of Vehicles									Total
	Bus/ Truck (>6000cc)	Car (Petrol)			Car(Diesel)		SUV <3000cc	3W	Scooter/ Motor cycle	
		<1000cc	1000- 1400cc	>1400cc	<1600cc	1600- 2400cc				
LINE8	101	81	63	16	218	5	56	86	527	1153
LINE9	61	53	54	11	107	7	53	51	411	808
LINE10	29	75	57	13	147	5	75	66	779	1246
LINE11	187	86	70	17	197	8	81	92	751	1489

Table 5.3: Emission Factors for different categories of vehicles

Emission factor (g/Km-vehicle)	Category of Vehicles								
	Bus/ Truck (>6000cc)	Car (Petrol)			Car(Diesel)		SUV <3000cc	3W	Scooter/ Motor cycle
		<1000cc	1000-1400cc	>1400cc	<1600cc	1600-2400cc			
CO	4.52	1.3	3.01	0.84	0.06	0.66	0.25	0.41	0.99
NOx	5.98	0.2	0.12	0.09	0.28	0.61	0.67	0.51	0.27
PM	0.67	0.004	0.006	0.002	0.015	0.18	0.096	0.091	0.02

Emission factor for bus/ Truck (>6000cc) was calculated by taking the average of emission factors of LCV Diesel (>3000cc), HCV diesel bus (>6000cc) and HCV diesel Truck (>6000cc). Likewise Emission factor for two wheeler was calculated by taking the average of Scooter (>80cc), Activa (>100cc) and Motor Cycle with varying capacity ranging from (<100cc, 100-200cc, >200cc).

Table 5.4 and Table 5.5 shows the calculated emission rate for the links for both the models and all the three main vehicular pollutant i.e. CO, NOx and PM.

Table 5.4: Emission rate for AERMOD and CALINE4 for self monitored links in Patiala city

Link_ID	Emission rate for AERMOD in g/sec			Emission rate for CALINE4 in g/mile-vehicle		
	CO	NOx	PM	CO	NOx	PM
LINE8	0.30	0.20	0.02	1.89	1.28	0.14
LINE9	0.69	0.42	0.05	1.93	1.17	0.12
LINE10	0.24	0.10	0.01	1.60	0.69	0.07
LINE11	1.25	0.94	0.10	2.16	1.63	0.17

Table 5.5: Emission rate for AERMOD and CALINE4 for major 17 links in Patiala city

Link_ID	Emission rate for AERMOD in g/sec			Emission rate for CALINE4 in g/mile-vehicle		
	CO	NOx	PM	CO	NOx	PM
LINE1	2.23	1.20	0.13	2.14	1.16	0.12
LINE2	0.95	0.79	0.09	2.92	2.46	0.27
LINE3	1.54	0.55	0.05	1.82	0.65	0.06
LINE4	1.50	1.05	0.11	2.47	1.72	0.18
LINE5	2.34	1.04	0.10	1.94	0.87	0.09
LINE6	3.22	2.71	0.29	2.89	2.43	0.26
LINE7	0.30	0.09	0.007	1.65	0.47	0.04
LINE8	0.38	0.26	0.03	2.45	1.69	0.18
LINE9	0.65	0.37	0.04	2.15	1.21	0.12
LINE10	0.26	0.11	0.01	1.87	0.79	0.08
LINE11	1.52	1.17	0.13	2.68	2.09	0.23
LINE12	1.91	1.45	0.16	2.65	2.01	0.22
LINE13	1.05	0.56	0.06	2.09	1.12	0.12
LINE14	0.57	0.36	0.04	2.27	1.39	0.15
LINE15	9.11	7.06	0.76	2.71	2.09	0.23
LINE16	0.93	0.27	0.02	1.63	0.47	0.04
LINE17	2.52	2.18	0.24	3.02	2.62	0.26

5.2 Meteorological processing

Mean hourly meteorological data January,2015 to April,2015 was collected from Weather Monitoring Station at Rooftop (D block) of Thapar University, Patiala.

AERMET View

The Surface data excel file was first converted to Samson format (.sam) and then imported to AERMET 8.8.9 view and Upper air data was estimated using upper air estimator option that estimates it from hourly surface data. Surface parameters (Albedo, Bowen ratio and surface roughness) values were selected as per land use of the Patiala city. Table 5.6 lists the Albedo, Bowen ratio and surface roughness that are assumed for this study. AERMET processes all the input data in three stages and generated two output files (surface file and profile file) and wind

rose plots (Figure 5.1). 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.

Table 5.6: Surface characteristics assumed for this study

Land use type	AERMOD		
	Albedo	Bowen Ratio	Surface roughness
Cultivable land	0.28	0.75	0.0725
Urban	0.2075	1.625	1

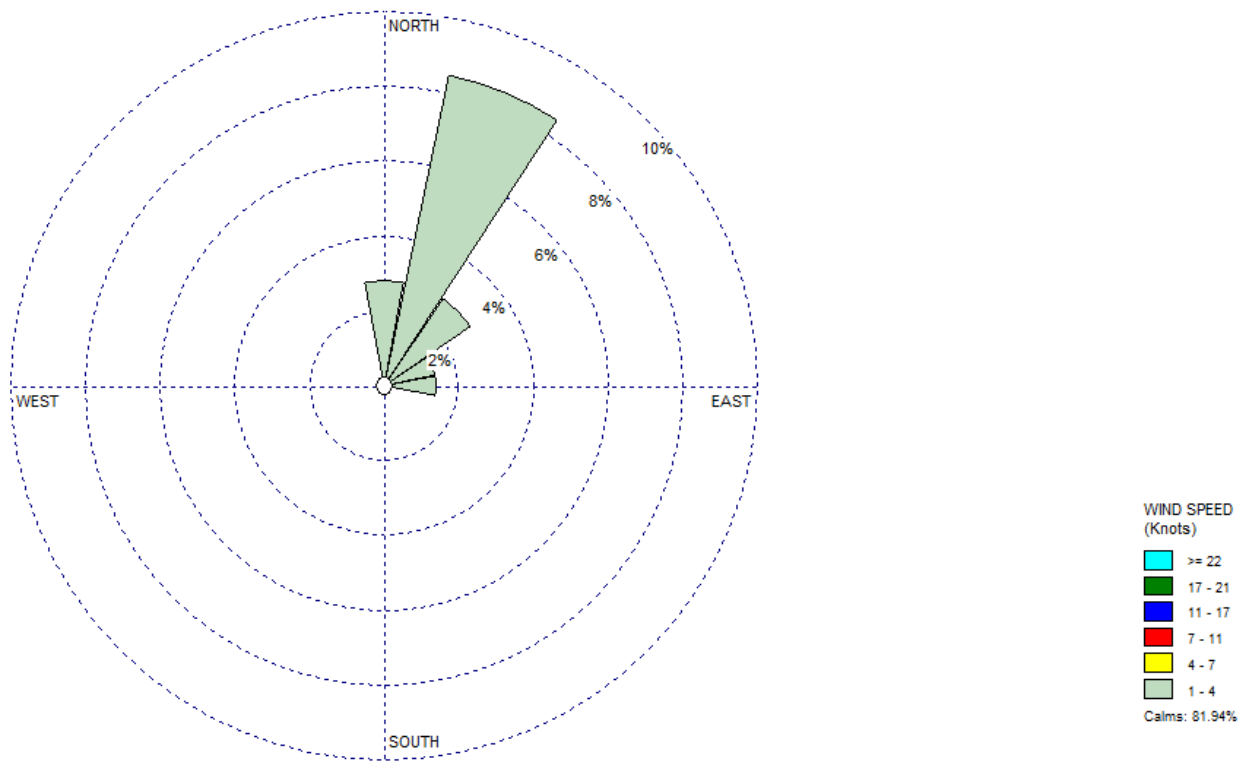


Figure 5.1: Wind rose in the study area for January, 2015 to April, 2015

Conventional wind rose depicts that the pre-dominant wind direction was from North-east with 81.94 % frequency of calm winds and the average wind speed was 0.37 Knots (1 Knot = 0.5144m/sec.). Hence, this pictorial view showed the dispersion of pollutants was towards West-

South side, the downwind distance upto which wind can cause pollutants to travel was further estimated with AERMOD and CALINE 4 along with pollutants concentrations.

5.3 Models Run

After obtaining all the data needed to simulate the pollutants (CO, NO₂ and PM) dispersion study in the study using AERMOD and CALINE4, the modeling results were depicted as isopleths. First of all base map of the study area was imported and with the help of UTM co-ordinates sampling sites and receptors were located. AERMOD has 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 is a flat terrain area and no building downwash was considered in this study. Source input for line source in AERMOD is given in Figure 5.2. The emission inventory was prepared for the 17 line sources.

The screenshot shows the 'Source Inputs' dialog box in AERMOD. The 'Source Type' is set to 'LINE'. The 'Source ID' is 'LINE17'. The 'Description' is 'Bus Stand chownk- dukhnivaran sahib'. The 'Source Location' fields are: X Coordinate: 634946.46 [m], Y Coordinate: 3357163.93 [m], Base Elevation: 258.0 [m], and Release Height: 0 [m]. The 'Source Release Parameters' fields are: Emission Rate: 0.000298 [g/sec-m²], X2 Coordinate: 634073.13 [m], Y2 Coordinate: 3358001.42 [m], Width: 7.0 [m], and Initial Vertical Dimension: [m] (Optional). The 'Area' fields show 8470.0 [m²] and 91170.2 [ft²]. The dialog box has a 'Help' button, a toolbar with navigation icons, and a 'Close' button.

Figure 5.2: Source input screenshot of AERMOD

CALINE4 has five mandatory pathways (Job, Meteorological, Output, Link and Receptor) and modeling was done for without canyon option for all the pollutants. Line source input screen specifying the link characteristics is shown in Figure 5.3.

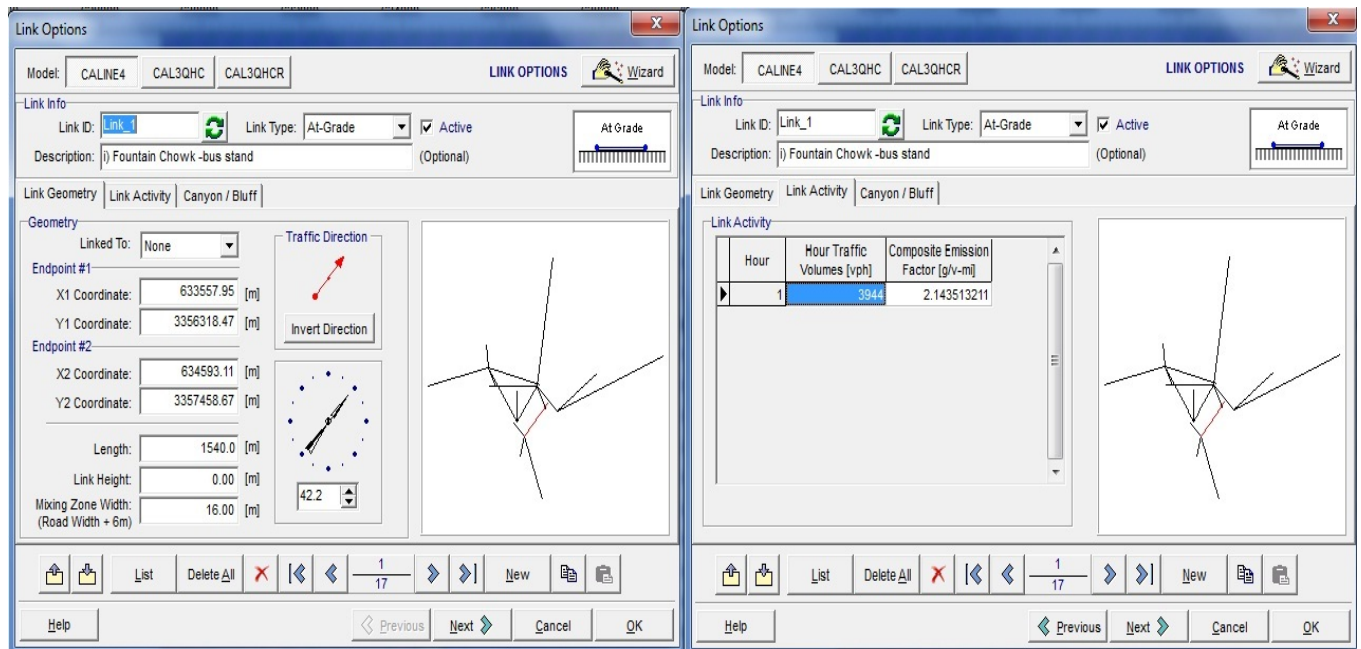


Figure 5.3: Source input screenshot of CALINE4

In the both modeling, the emission factor was actually for total NO_x (NO + NO₂) however the National Ambient Air Quality Standard is for NO₂ alone. Although automobiles and other combustion sources typically emit NO_x as 90-95% NO, and only 5-10% NO₂, volatile organic compounds can oxidize NO in the atmosphere to NO₂. Thus, using the NO_x emission factor to represent NO₂ emissions was conservative, assuming that VOCs in the atmosphere oxidized all NO emitted to NO₂ (Bhatt et al. 2013).

5.4 Model predictions (All the major links of Patiala City)

With the help of UTM co-ordinates, sampling sites and five discrete Cartesian receptors were located and the above mentioned parameters were set in the models pathways and models were successfully run and the GLC of pollutants including CO, NO₂ and PM were predicted.

5.4.1 Models predictions for CO

Figure 5.4 and 5.5 shows isopleths of the 1 h averaging CO ground level concentration from line source predicted by AERMOD and CALINE 4 respectively. AERMOD shows the maximum GLC of 5.21 ppm while, CALINE 4 shows maximum GLC of 0.9 ppm at receptor 5 i.e. Kali Mata Mandir located at road connecting Fountain chowk to Bus stand (Link1).

5.4.2 Models predictions for NO₂

Vehicular emission dispersion modeling for NO₂ was carried for 1 h averaging option considering all the assumptions using two steady state models based on Gaussian equation i.e. AERMOD and CALINE4. Figure 5.6 and 5.7 depicts the contour plots generated showing minimum to maximum GLC by AERMOD and CALINE4 respectively. AERMOD predicts the maximum GLC of 4.66 ppm whereas, CALINE 4 predicts the maximum GLC of 0.06 ppm at receptor 5 i.e. Kali Mata Mandir located at road connecting Fountain chowk to Bus stand (Link1).

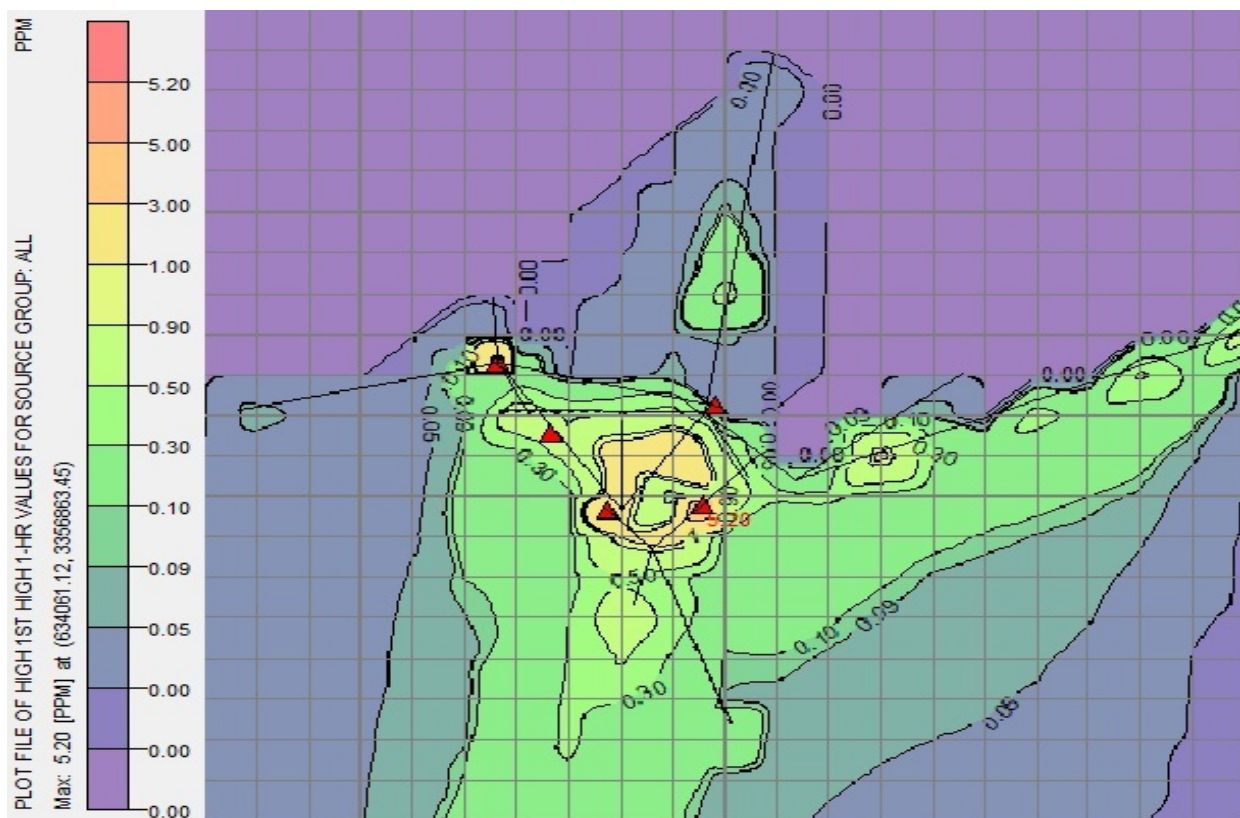


Figure 5.4: AERMOD 1 h averaging ground level concentrations of CO (ppm)

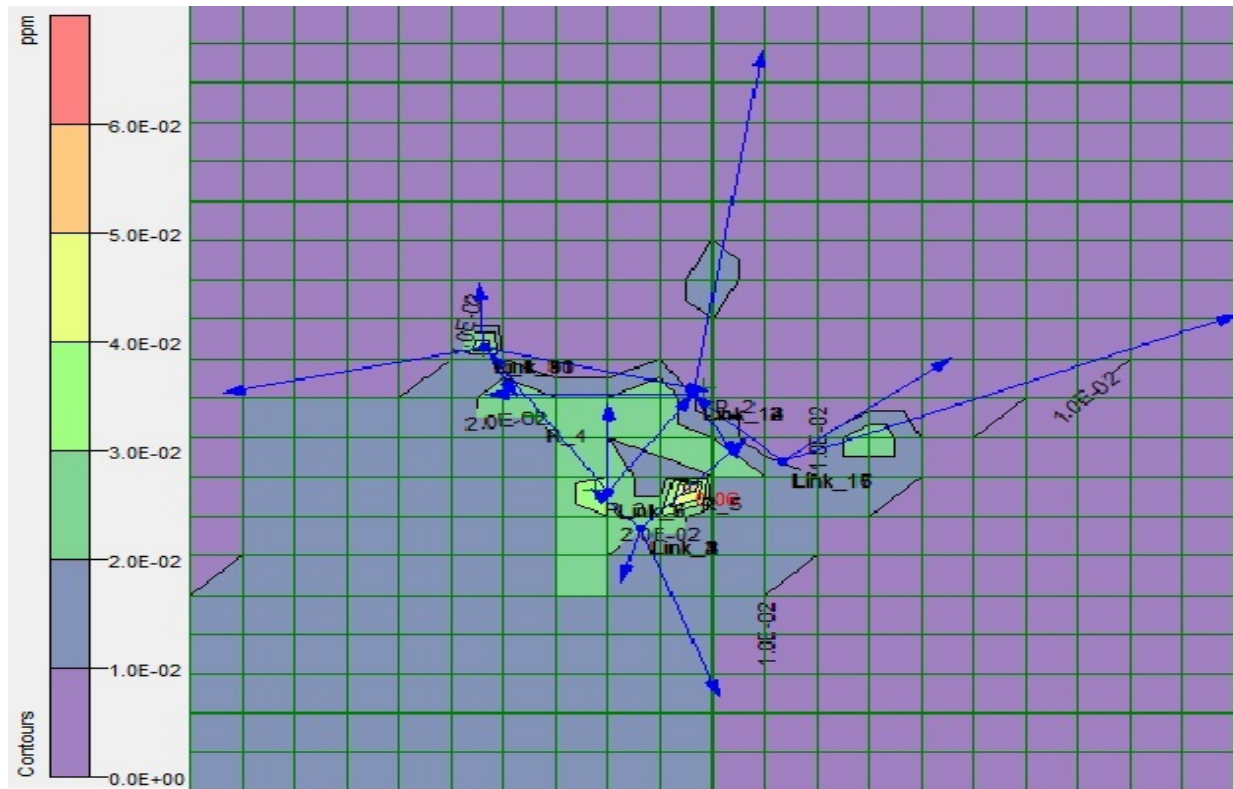


Figure 5.7: CALINE4 1 h averaging ground level concentrations of NO₂ (ppm)

5.4.3 Models prediction for PM

Air dispersion modeling results for incremental ground level concentration of particulate matter on considering the line sources are presented in Figure 5.8 and 5.9 according to 1 h averaging options. Figure 5.8 shows the maximum GLC predicted by AERMOD is 709.39 $\mu\text{g}/\text{m}^3$ and maximum concentration was predicted along link 15 connecting Bus Road Chowk to Rajpura road. Figure 5.9 shows prediction by CALINE4 and maximum predicted GLC is 56.8 $\mu\text{g}/\text{m}^3$ at receptor 5 i.e. Kali Mata Mandir located at road connecting Fountain Chowk to Bus stand (Link1). AERMOD predictions were higher than CALINE4 predicted concentrations.

From the isopleths, it is observed that maximum pollutant dispersion by both models is seen in downwind direction i.e. south-west side and very rare dispersion in crosswind direction. No pollutant dispersion is seen in upwind direction. Maximum pollutant concentration estimated by both the models for the pollutants was observed in downwind direction. In findings of *Noll et al.(1978)* it was observed that line source model CALINE and CALINE 2 overestimate concentrations for parallel wind conditions and underestimate for oblique and crosswind conditions.

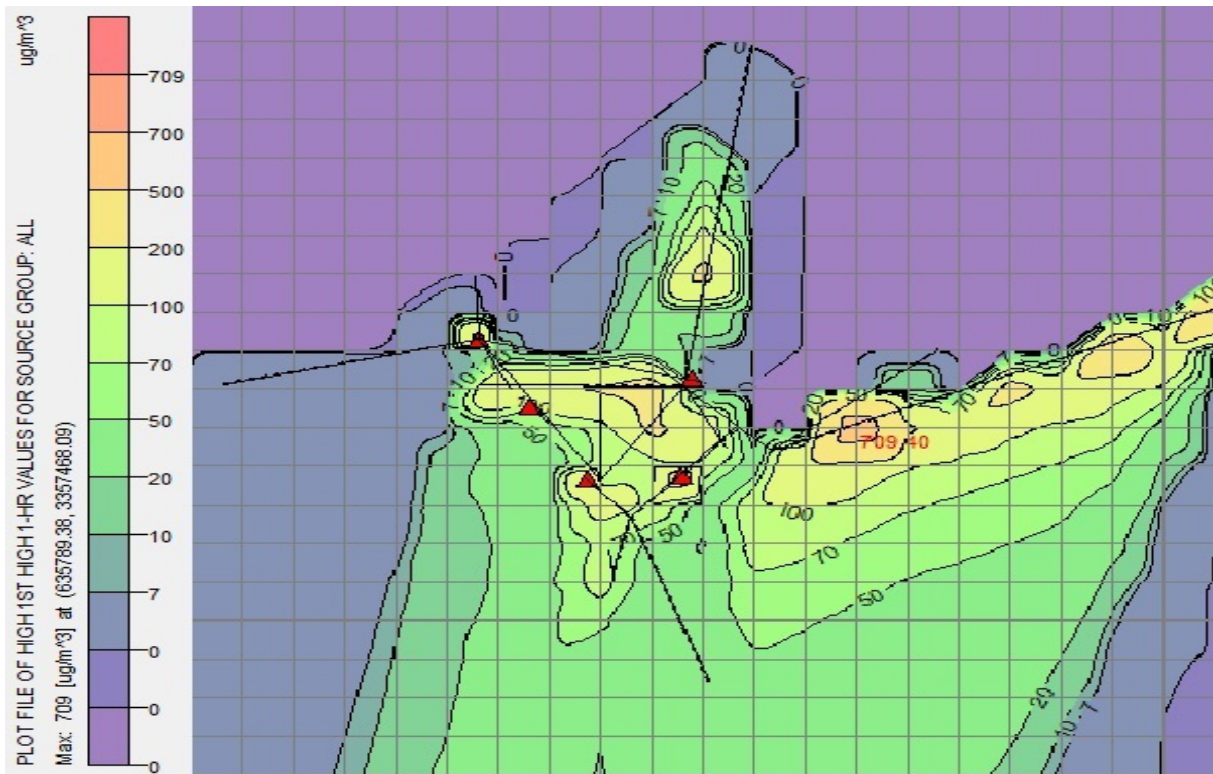


Figure 5.8: AERMOD 1 h averaging ground level concentrations of PM ($\mu\text{g}/\text{m}^3$)

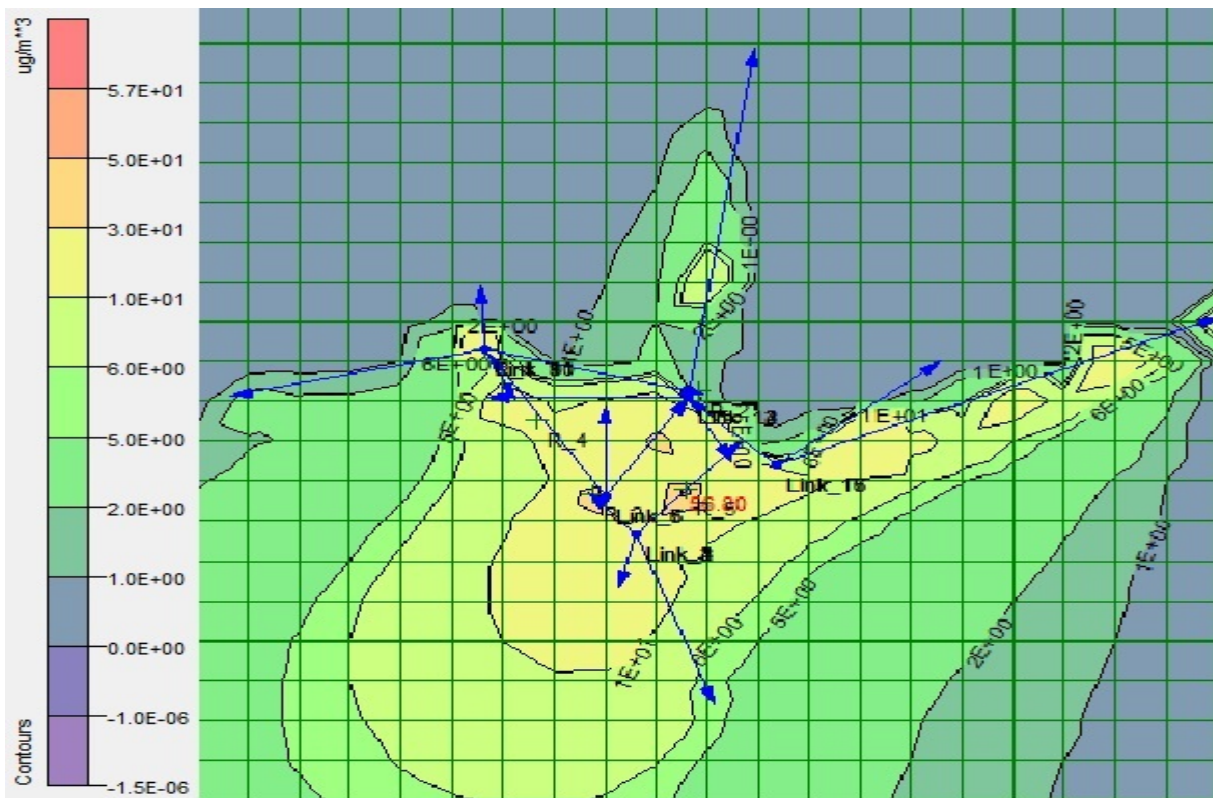


Figure 5.9: CALINE4 1 h averaging ground level concentrations of PM ($\mu\text{g}/\text{m}^3$)

5.4.4 Comparison of AERMOD and CALINE4

Maximum incremental value prediction for all the 3 pollutants namely CO, NO₂ and PM were carried out using AERMOD and CALINE4 at 5 discrete receptors located in the Patiala. Ground level concentration predicted by models differs at all the receptors. Table 5.7 summarizes the concentrations predicted by the models.

Table 5.7: Predicted maximum incremental GLC by CALINE4 and AERMOD

Receptors	CO(ppm)		NO ₂ (ppm)		PM (µg/m ³)	
	AERMOD	CALINE4	AERMOD	CALINE4	AERMOD	CALINE4
Thapar University	3.83	0.3	4.3	0.037	250.56	28.1
Gurdwara Dukhnivaran Sahib	0.02	0.0	0.03	0	14.75	1.8
Gopals Sweets	2.15	0.5	2.65	0.037	187.54	38.7
Columbia Asia Hospital	0.66	0.2	0.52	0.017	73.70	12.2
Kali Mata Mandir	5.20	0.9	4.66	0.057	288.20	56.8

For all the pollutants AERMOD showed higher concentration than CALINE4 at all receptors.

5.5 Model prediction (For self monitored road links)

Model prediction were carried out using 4 different links.

5.5.1 Models predictions for CO

Figure 5.10 and 5.11 shows isopleths of the 1 hr averaging CO ground level concentration from line source predicted by AERMOD and CALINE 4 respectively. AERMOD shows the maximum GLC of 3.09 ppm while, CALINE 4 shows maximum GLC of 0.3 ppm at Thapar University.

5.5.2 Models predictions for NO₂

Vehicular emission dispersion modeling for NO₂ was carried for 1 h averaging option considering all the assumptions using two steady state models based on Gaussian equation i.e. AERMOD and CALINE4. Figure 5.12 and 5.13 depicts the contour plots generated showed minimum to maximum GLC by AERMOD and CALINE4 respectively. AERMOD predicts the maximum GLC of 3.59 ppm whereas, CALINE 4 predicts the maximum GLC of 0.03 ppm at Thapar University. *Koe et al. (2005)* also documented that CALINE4 were found in good agreements with CO and NO₂ for flat, fill and bridge road types.

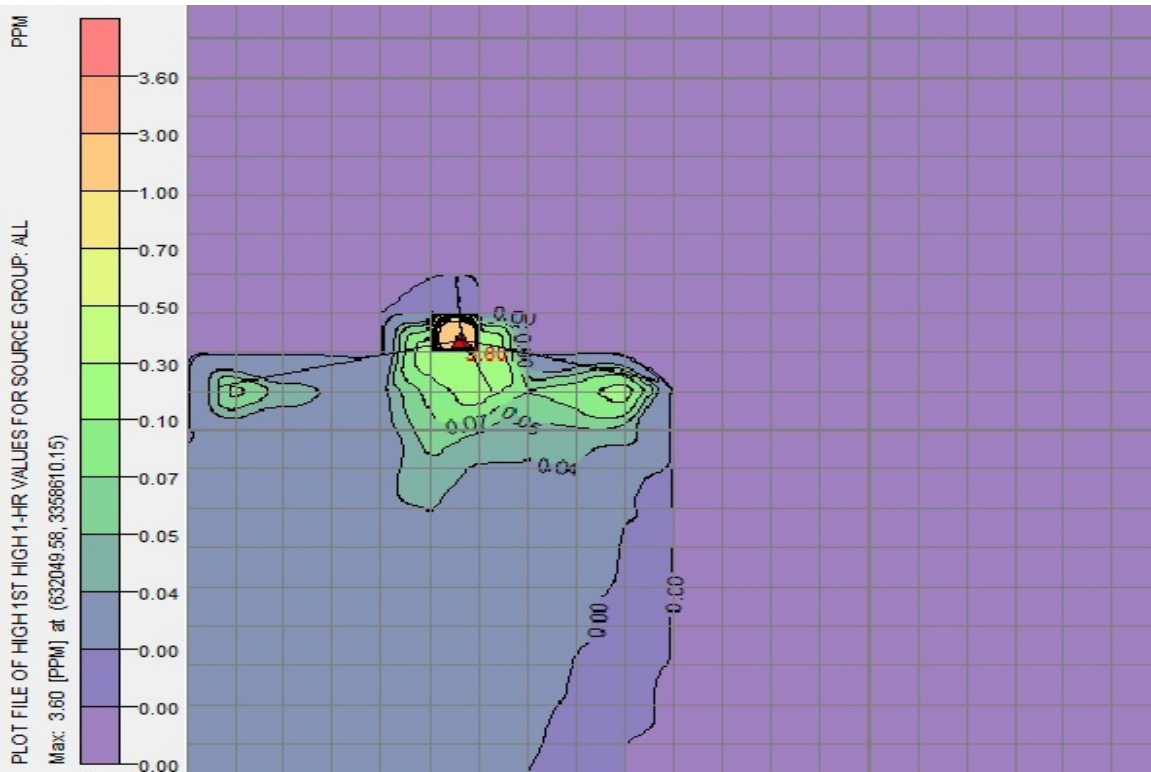


Figure 5.12: AERMOD 1 h averaging ground level concentration of NO₂ (ppm)

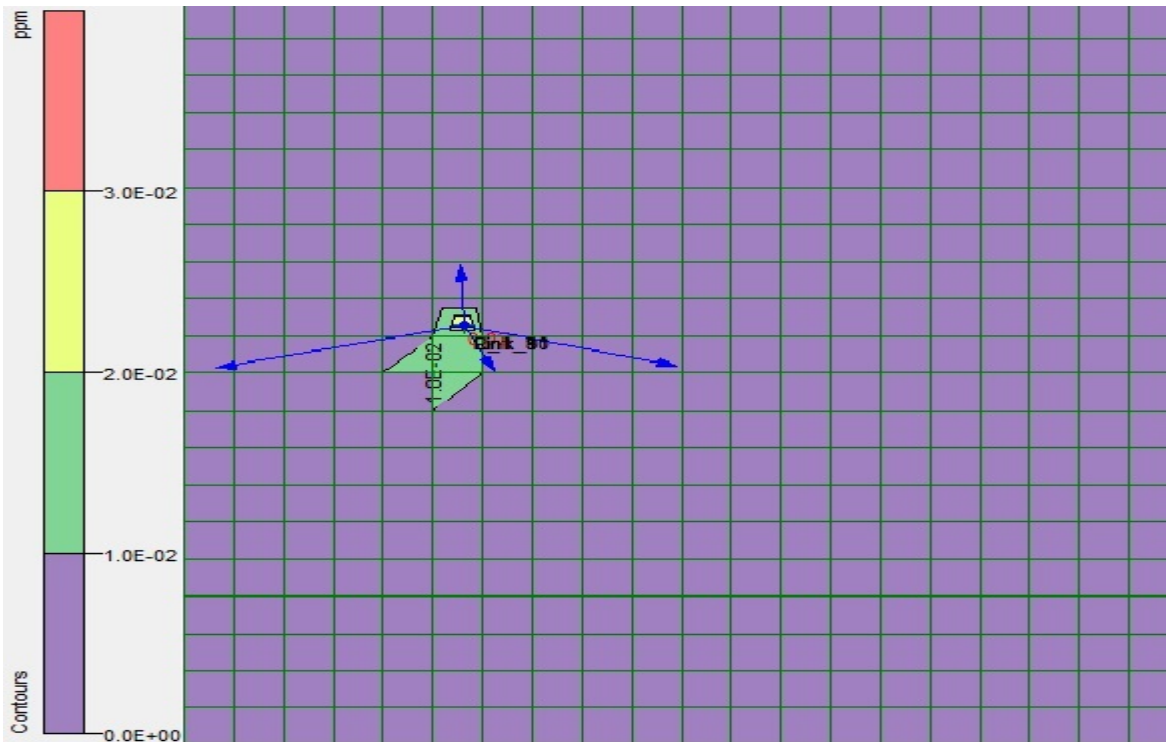


Figure 5.13: CALINE4 1 h averaging ground level concentration of NO₂ (ppm)

5.5.3 Models prediction for PM

Air dispersion modeling results for incremental ground level concentration of particulate matter on considering the line sources are presented in Figure 5.14 and 5.15 according to 1 h averaging options. Figure 5.14 shows the maximum GLC predicted by AERMOD is $199.84 \mu\text{g}/\text{m}^3$ and Figure 5.15 shows prediction by CALINE4 and maximum predicted GLC is $21.9 \mu\text{g}/\text{m}^3$ at Thapar University. AERMOD predictions are higher than CALINE4 predicted concentrations. CALINE4 is used to predict particulate matter (*Gramotnev et al.(2003), Koe et al., (2005)*) and found in good agreements with measured value.



Figure 5.14: AERMOD 1 h averaging ground level concentrations of PM ($\mu\text{g}/\text{m}^3$)

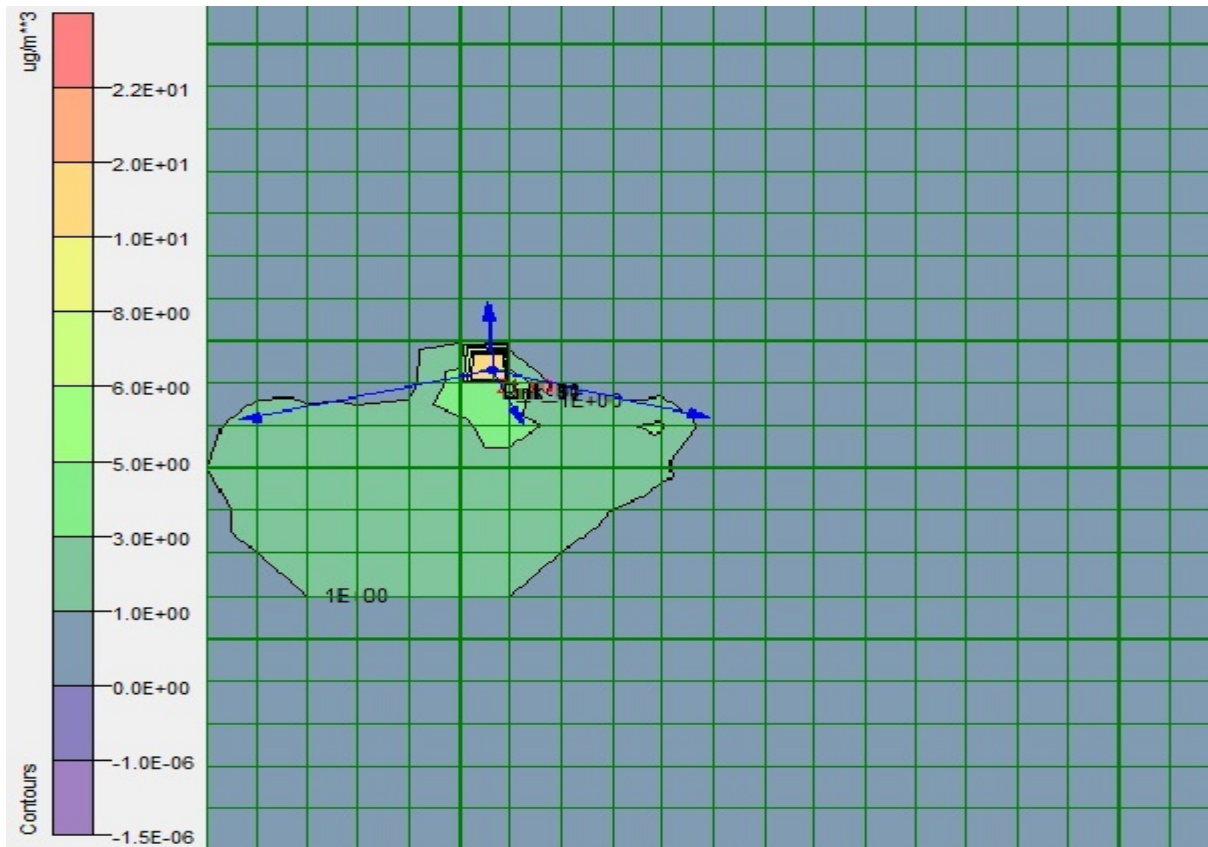


Figure 5.15: CALINE4 1 Hr averaging ground level concentrations of PM ($\mu\text{g}/\text{m}^3$)

5.6 Performance evaluation of the models

It is imperative that these dispersion be properly evaluated with the observational data before their predictions can be used with confidence because the model result often influence decisions that have large public health and economic consequences. For statistical evaluation, the predictions are evaluated against some reference states, i.e., observations which are directly measured using instruments. Various statistical descriptors mainly: Index of agreement (d), Fractional Bias (FB), Normalized Mean Square Error (NMSE), Geometric Mean Bias (MG), and the fraction of predictions within a factor of two of observations was recommended by Hanna et al., (1993) for the evaluation of model performance. For an ideal prediction, the value of MG has to be 1.0 and the values of FB and NMSE=0.0. For a dataset, where both predicted and observed concentrations vary by many orders of magnitude, MG is more appropriate. The performance of the model would be acceptable if $\text{NMSE} \leq 1.5$; $-2 \leq \text{FB} \leq 2$ and $0.5 \leq \text{FAC2} \leq 2$. Table 5.8- 5.10 shows the model performance. Model acceptance criteria for CO are shown in Table 5.8.

Table 5.8 Statistical performance of CALINE4 and AERMOD for CO prediction

Model	Predicted Concentration (ppm)	Measured Concentration (ppm)	Normalized Mean Square Error (NMSE)	Fractional Bias	FAC2
CALINE	0.3	0.71	0.78	0.81	0.42
AERMOD	3.09	0.71	2.62	-1.26	4.39

Table 5.9: Statistical performance of CALINE4 and AERMOD for NO₂ prediction

Model	Predicted Concentration (ppm)	Measured Concentration (ppm)	Normalized Mean Square Error (NMSE)	Fractional Bias	FAC2
CALINE	0.03	0.016	0.33	-0.55	1.77
AERMOD	3.59	0.016	209.89	-1.98	211.89

Table 5.10: Statistical performance of CALINE4 and AERMOD for PM prediction

Model	Predicted Concentration (µg/m ³)	Measured Concentration (µg/m ³)	Normalized Mean Square Error (NMSE)	Fractional Bias	FAC2
CALINE	21.9	42.7	0.46	0.64	0.51
AERMOD	199.8	42.7	2.89	-1.29	4.68

Table 5.11: Model performance evaluation for CO prediction

CO Prediction Test		
Test	AERMOD	CALINE4
$0.5 \leq \text{FAC2} \leq 2$	NO	NO
$-2 \leq \text{FB} \leq 2$	OK	OK
Random scatter (NMSE <1.5)	NO	OK
Acceptance	NO	OK

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 point sources). CALINE 4 performed better in comparison to AERMOD for 1 h prediction of CO concentration which were similar to findings done in earlier studies by *Dubey et al., (2013)* on the basis of statistical descriptors as shown in Table 5.11. It is evident that AERMOD line source model is over predicting the concentration of CO pollutant. Though, 1 h averaging concentrations predicted by both the models are below NAAQS. Model performance check for NO₂ is given in Table 5.12.

Table 5.12: Model acceptance test for NO₂

NO ₂ Prediction Test		
Test	AERMOD	CALINE4
$0.5 \leq \text{FAC2} \leq 2$	NO	OK
$-2 \leq \text{FB} \leq 2$	OK	OK
Random scatter (NMSE <1.5)	NO	OK
Acceptance	NO	OK

CALINE 4 performed better in comparison to AERMOD for 1 h prediction of NO₂ concentration on the basis of statistical descriptors as shown in Table 5.12. It is evident that NO₂ concentrations predicted by CALINE 4 is below the NAAQS while AERMOD line source model is over predicting the 1 h averaging concentration and is exceeding the prescribed standards. Similarly CALINE 4 performed better in comparison to AERMOD for 1 h prediction of PM concentration on the basis of statistical descriptors as shown in Table 5.13.

Table 5.13: Model acceptance test for PM

PM Prediction Test		
Test	AERMOD	CALINE4
$0.5 \leq \text{FAC2} \leq 2$	NO	OK
$-2 \leq \text{FB} \leq 2$	OK	OK
Random scatter (NMSE <1.5)	NO	OK
Acceptance	NO	OK

CALINE4 under predicts the ground level concentration while, AERMOD highly overestimates the near road particulate concentration in comparison with measured value. Overall performance of CALINE4 prediction for near road pollutant concentrations is better than AERMOD for 1 h prediction. CALINE 4 functioning is better under stable atmospheric conditions but performed poorly under low wind conditions (*Broderick et al.(2005)*). In this study moderately stable conditions was assumed and predicted concentrations are satisfying the model acceptance criteria. Also, model performance is better with canyon conditions than without canyon for NO₂ conditions because of proper consideration of deterioration rate (*Konar and Chakrabarty, (2012)*).

The CALINE 4 model has better performance than other line source models and is widely used to predict near road vehicle emissions (*Nagendra and Khare, 2002*). It embeds the concept of mixing zone and uses modified Gaussian plume distributions (*Benson, 1984*). Also AERMOD is based on Gaussian plume dispersion but it is has wide application and mainly used for mainly large areas (*Faulkner et al., 2007, Kumar et al., 2006*) while CALINE 4 is mainly for near road pollutants and reliable upto 500 m (*Majumdar et. al., 2010*). This may be reason for varied prediction by both the models.

CHAPTER 6

CONCLUSIONS

In the present study, the effect of the air quality of Patiala city was observed due to increasing number of vehicular traffic. Using the emission inventory of major roads of Patiala city as a source data, ground level concentration of CO, NO₂ and PM were estimated by using U.S. EPA approved dispersion models; AERMOD which is Gaussian plume dispersion model and CALINE4 which is traffic dispersion model. The dispersion model results were then compared with each other in order to check the efficacy of these two models. Moreover, the model predictions were also compared with the ambient air measurements to determine the accuracies of the models. Ambient air monitoring of NO₂ and PM were carried out at Thapar University while the ambient air data of CO were acquired from Indian Institute of Tropical Meteorology, Pune continuous ambient air monitoring station located at Thapar University. This real data was used to validate the models on the basis of statistical descriptors.

Mean hourly meteorological data was collected by Weather Monitoring Station which was imported by AERMET view. Based on wind data, population density, topography and other local parameters of study area receptor were selected on which maximum GLC was predicted. With all the specified conditions, both the models were run to generate isopleths showing the minimal to maximal concentration of pollutants in the study area. The spatial distribution of the maximum incremental concentration for line source shows AERMOD predicted higher incremental concentrations in downwind direction than CALINE4 in both 17 links and 4 links studies for all the vehicular pollutants for 1 h averaging period. GLC obtained with two dispersion models were not only compared with each other but also compared with the ambient air pollutants measurements at given receptor for model acceptance. CALINE4 model under predicts CO and PM concentration w.r.t measured concentration and slightly over predicts for NO₂ which may be due to non consideration tall buildings effects whereas AERMOD over predicts in all the cases for which one of the possible reason is the AERMOD assumes uniform emissions for all the h of the day which is not same as no. of vehicles vary continuously with time so emissions will be different for each h. Therefore, variable emission factor for each h need to be specified.

Overall results of CALINE4 performance are satisfactory in model acceptance criteria than AERMOD. Thus CALINE4 model is more validate in nature hence, the CALINE4 seems to be more accurate in predicting GLC for line sources in comparison to AERMOD.

CHAPTER 7

FUTURE RECOMMENDATIONS

The present study covers the aspects of air quality modeling using EPA approved dispersion models namely; CALINE4 and AERMOD in the study area. The study was done without considering the effects of buildings on pollutant dispersion in the city. Therefore, further refinement in the study can be carried out by considering the canyon effects for line sources in the model run. Also, specifying variable emission factor for each h of the day in AERMOD will give more comparable results with the CALINE4.

Very limited studies have been carried out using AERMOD and line source dispersion model. AERMOD comparison can also be studied with CAL3QHC and CAL3QHCR. Also modification in the existing line source dispersion model can be done on the basis of existing traffic and meteorological conditions to improve the performance of the models.

AERMET model algorithm should be reviewed to improve the model performance during prolonged stagnant conditions like calm conditions, as the results from the AERMET showed calm period was 81.94 %. Since skipping the meteorological hours with calm conditions may affect the overall performance of the model.

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ANNEXURE I

National Ambient Air Quality Standards (NAAQS)- 2009 through Govt. Gazette

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*	50	20	- Improved West and Gaeke - Ultraviolet fluorescence
		24 hours**	80	80	
2	Nitrogen Dioxide (NO ₂), =µg/m ³	Annual*	40	30	- Modified Jacob & Hochheiser (Na-Arsenite) -Chemiluminescence
		24 hours**	80	80	
3	Particulate Matter (size less than 10=µm) or PM10 = µg/m ³	Annual*	60	60	- Gravimetric - TOEM - Beta attenuation
		24 hours**	100	100	
4	Particulate Matter (size less than 2.5=µm) or PM2.5=µg/m ³	Annual*	40	40	- Gravimetric - TOEM - Beta attenuation
		24 hours**	60	60	
5	Ozone (O ₃) =µg/m ³	8 hours**	100	100	- UV photometric - Chemiluminescence -Chemical Method
		1 hour**	180	180	
6	Lead (Pb) =µg/m ³	Annual*	0.50	0.50	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper - ED-XRF using Teflon filter
		24 hours**	1.0	1.0	
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 - Indophenol blue Method
		24 hours**	400	400	
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/m3	Annual*	01	01	- Solvent extraction followed by HPLC/GC analysis
11	Arsenic (As),ng/m3	Annual*	06	06	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper
12	Nickel (Ni), ng/m3	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.

PUBLICATIONS/ CONFERENCE ATTENDED

Goyal, U. and Dhir, A. (2015); Monitoring of particulate matter at greater Mohali and its associated health impacts. National Seminar on Environmental Management, Sustainable Development and Human Health, Organized by Dr S S Bhatnagar University Institute of Chemical Engg. & Technology, Panjab University, Chandigarh.

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3	Particulate Matter (size less than 10=µm) or PM10 = µg/m ³	Annual*	60	60	- Gravimetric - TOEM - Beta attenuation
		24 hours**	100	100	
4	Particulate Matter (size less than 2.5=µm) or PM2.5=µg/m ³	Annual*	40	40	- Gravimetric - TOEM - Beta attenuation
		24 hours**	60	60	
5	Ozone (O ₃) =µg/m ³	8 hours**	100	100	- UV photometric - Chemiluminescence -Chemical Method
		1 hour**	180	180	
6	Lead (Pb) =µg/m ³	Annual*	0.50	0.50	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper - ED-XRF using Teflon filter
		24 hours**	1.0	1.0	
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 - Indophenol blue Method
		24 hours**	400	400	
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.

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