Comparative studies of air pollution modelling techniques from a point source(s) of Thermal Power Plant

A Dissertation

submitted in partial fulfilment of the requirement

for the award of degree of

Masters in Technology

in

Environmental Science and Technology

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July 2014

CERTIFICATE

This is to certify that thesis entitled, **"Comparative studies of air pollution modelling techniques from a point source(s) of Thermal Power Plant"** submitted by **Mr. Rahil Changotra** in partial fulfilment of the requirements for the award of **Masters in Technology** Degree in **Environmental Science & Technology** at **Thapar University, Patiala** is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this thesis has not been submitted to any other university/ institute for award of any Degree or Diploma.

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DECLARATION

I, the undersigned, hereby declare that the research work presented in the M.Tech project entitled "**Comparative studies of air pollution modelling techniques from a point source(s) of Thermal Power Plant**" has been carried out by me under the supervision and guidance of ***Dr. Amit Dhir, Assistant Professor, School of Energy and Environment, Thapar University, Patiala***.

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

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ABSTRACT

Increase in technological, industrial and agricultural advancement, coupled with increase in population growth, has deteriorated the air quality throughout the different cities of the world. Rapidly growing cities, more traffic on roads, growing energy consumption, waste production and lack of strict implementation of environmental regulation are the reasons for the increase in the discharge of pollutants into the atmosphere. People are entirely dependent on continuous supply of energy for most of the everyday activities, therefore, in order to meet this increasing demand on energy, government and private sectors are investing huge amount of money in energy production, especially on electricity generation. Electricity generation through thermal power plants (TPPs) in India has increased manifold in the recent decades to meet the demand of the increasing population. Combustion process in TPPs converts coal into useful heat energy, but it also emits carbon dioxide (CO_2), sulphur oxides (SO_x), nitrogen oxides (NO_x); CFCs besides air borne inorganic particulates, such as fly ash and suspended particulate matter (SPM). Thus, Thermal Power Plants (TPPs) have been found to affect air quality of the surrounding region adversely.

In the present study, attempt has been made to compare two air quality dispersion models in predicting the air quality by taking into account the emissions of thermal power plant. The emission inventory was prepared for Rajpura Thermal Power Plant. Stack monitoring was carried out to monitor the emissions from the thermal power plant and additional emission inventory was prepared for two other large scale industries in the study area to differentiate the effect of thermal power plant alone. Mean hourly meteorological data for one year period January, 2013 to December, 2013 was collected from Weather Monitoring Station and Upper air for the same year was collected from IMD, Pune which was imported to RAMMET View and AERMET View. Based on wind data, population density, topography and other local parameters of study area eight receptors were selected on which maximum incremental Ground Level Concentrations (GLCs) of SO_2, NO_2 and SPM were predicted by using EPA approved dispersion models; namely ISCST3 and AERMOD. GLCs predicted by two models were compared and the models were validated with the results of actual ambient air monitoring at the receptors site. The spatial distribution of the maximum incremental concentration for the point sources of TPP

shows AERMOD predicted higher incremental concentrations near to the source as compared to ISCST3 for annual and daily (24 h) averaging periods. Considering additional major industrial sources, the predicted GLCs of both the models were almost similar to the results as predicted during the modelling of TPP alone. Thus, results depicts that the major source of air pollution in the region is Thermal Power Plant.

Validation of models prediction with ambient air measurements was done for both ISCST3 and AERMOD and the models were observed to underestimate the observed ground level concentration of NO_2 and SO_2 for the nearby receptors to the thermal power plant and for SPM; predictions of both ISCST3 and AERMOD were underestimating the observed ground level concentration of SPM at all the receptors. This is probable because the building downwash and emission from mobile sources were not taken into consideration in the models run. Overall results of AERMOD seem to be good in correlation graphs when compared to ISCST3 with higher coefficient of correlation value for AERMOD. Thus, AERMOD model is more validate and accurate in predicting the GLCs at various receptors.

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AERMIC	American Meteorological Society/Environment Protection Agency Regulatory Model Improvement Committee
AERMOD	American Meteorological Society/Environmental Protection Agency Regulatory Model
AMS	American Meteorological Society
APCA	Air Pollution Control Association
CBL	Convective Boundary Layer
CPCB	Central Pollution Control Board
EIA	Energy Information Administration
EPA	Environmental Protection Agency
ESP	Electrostatic Precipitator Units
FGD	Flue Gas Desulphurization Units
GFLSM	Gaussian Finite Line Source Model
GLC	Ground Level Concentration
GMT	Greenwich Mean Time
GWh	Gigawatt hour
IMD	Indian Meteorological Society
ISCST3	Industrial Source Complex - Short Term Version 3
LPM	Litre Per Minute
MWe	Megawatt Electricity
NAAQM	National Ambient Air Quality Monitoring
NAMP	National Air Quality Monitoring Programme
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Co-operation and Development
PAHs	Polycyclic Aromatic Hydrocarbons
PBL	Planet Boundary Layer
PM	Particulate Matter
PPCB	Punjab Pollution Control Board
PRIME	Plume Rise Model Enhancements
RSPM	Respirable Suspended Particulate Matter
SBL	Stable Boundary Layer
SECL	South Eastern Coal Limited
SHW	State Hydraulic Works
SPO	State Planning Organization
TSP	Total Suspended Particulates
U.S.A.	United States of America
VOCs	Volatile Organic Compounds
WHO	World Health Organization

CHAPTER 1

AIR QUALITY

One can survive without water for a few days, but one cannot live without breathing air even for a few moments. The air that we breathe directly gets into our bloodstream; hence it is necessary for us to ensure that the air is not polluted beyond the threshold limits. Owing to technological, industrial and agricultural advancement, coupled with increases in population growth, leads to deteriorated air quality throughout the world. Rapidly growing cities, more traffic on roads, growing energy consumption, waste production, and lack of strict implementation of environmental regulation are increasing the discharge of pollutants into the atmosphere.

1.1 Overview

Energy is an indispensable fundamental input to modern life. People are entirely dependent on continuous supply of energy for most of the everyday activities. Our dependency on energy is increasing significantly every year. Therefore, energy became the primary factor of specifying governments, political, economical and social strategies. In order to meet this increasing demand on energy, government and private sector are investing huge amount of money in energy production. Especially, they are focusing on electricity generation. World electricity consumption is expected to double between the years 2003 and 2030 according to the projections of IEO2006. Non-OECD (Organization for Economic Co-operation and Development) countries will account for 71 percent of this projected growth, and OECD countries account for the 29 percent. Today, more than 60% of the world electricity generation is being supplied by fossil fuels. In the near future, considerable change in this profile is not expected *(EIA, www.eia.doe.gov)*.

Energy production and use can affect the environment in many ways, with every diverse impact from different fuel sources. Burning fossil fuels for electricity generation results in significant air pollution. Types and amount of the air pollutants emitted depend on the type of combustion process, on the fuel and on processing of combustion gases *(Baumbach, 1996)*. Moreover, the electricity sector is the most important air pollution source among industrial sectors. Electricity generation produces a large amount of nitrogen oxides (NO_x), sulphur dioxide (SO_2), particulate matter (PM), carbon monoxide (CO), hydrocarbons (HC), soot and other pollutants emissions as depicted in Figure 1.1.

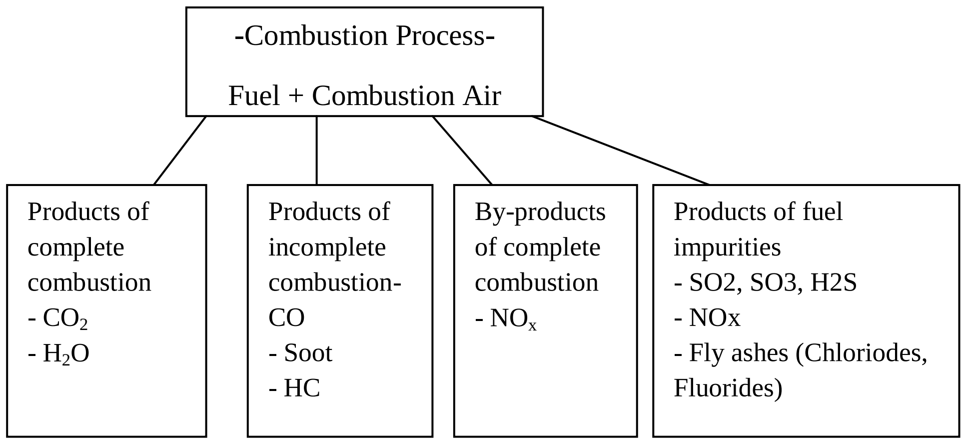

Figure 1.1 Air pollutants from combustion of fuels *(Baumbach, 1996)*

The levels of air pollutants are rapidly increasing in urban and rural areas. Most Asian cities cannot 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. The burning of fossil fuels is also the major source of carbon dioxide (CO_2) emissions, a primary contributor to global warming. Motor vehicles emit particulate matter (PM), NO_2 and NO (together referred to as NO_x), carbon monoxide, organic compounds, and lead. The chemical composition of the atmosphere is being altered/changed by the addition of all these gases, particulates and volatiles substances, which may be toxic to living beings. The air pollutants so generated are detrimental to human health. In addition, they cause negative impacts directly or indirectly, if at elevated concentrations, on vegetation, animal life, buildings and monuments, weather and climate, and on the aesthetic quality of the environment.

The World Health Organization estimates that air pollution contributes to approximately 800,000 deaths and 4.6 million lost life years annually *(World Health Report 2002).* 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).* To date, estimates of the health effects resulting from exposure to air pollution in Asia have relied largely on the extrapolation of results from research conducted outside Asia primarily in Europe and North America *(National Environment Protection Council, 2010*). India need to generate regular information on the ambient concentration levels of small particulates of diameter less than 10 micron and/or 2.5 micron and take urgent steps to control emissions of these particles *(Urban air pollution, 1999).* Table 1.1 shows the major air pollutants and their effect on public health.

Table 1.1 Major air pollutants and their effect on public health *(Source: WHO)*

Outdoor Air Pollutant	Major Health Concern	Pollutant Source(s)
Suspended particulate matter (SPM, PM_{10}, $PM_{2.5}$)	Disrupts lung's gas exchange function and cause respiratory illness	Mixture of solid and liquid organic plus inorganic materials including sulfate, nitrates, ammonia, sodium chloride, carbon, mineral dust and water.
Ozone (O_3)	Increase respiratory infections (colds, pneumonia), breathing difficulties and asthma	Part of photochemical smog produced by the interaction of sunlight and air pollutants
Nitrogen dioxide (NO_2)	Long-term intake is toxic, reduce lung function and cause bronchitis in asthmatic children	Part of PM2.5 and O3, found in nitrate aerosols, produced by burning fuels, electricity generation plus vehicles engines
Sulphur dioxide (SO_2)	10 minute exposure decreases pulmonary function. Causes eye irritation and respiratory inflammation (coughing, infections, mucus secretion, asthma attacks, bronchitis)	Burning fossil fuels and industrial processes
Carbon dioxide (CO_2)	Lower oxygen levels, reduce respiratory and brain functions, cause vision defects	Burning coal, oil and natural gases
Carbon monoxide (CO)	Lowers blood oxygen levels, slow reflexes, increase confusion and sleepiness	Cigarettes plus burning petrol, diesel, and wood
Lead (Pb)	Damages nervous system in children	Petrol, diesel, lead batteries, paints, and coloring agents

1.2 Air quality status in India

Rapid urbanization and industrialization has added various pollutants to the air and thus caused deterioration of air quality in India. In order to prevent, control and abate air pollution, the Air (Prevention and Control of Pollution) Act was enacted in 1981. According to Section 2(b) of Air (Prevention and control of pollution) Act, 1981 'air pollution' has been defined as 'the presence in the atmosphere of any air pollutant.' As per Section 2(a) of Air (Prevention and control of pollution) Act, 1981 'air pollutant' has been defined as 'any solid, liquid or gaseous substance [(including noise)] present in the atmosphere in such concentration as may be or tend to be injurious to human beings or other living creatures or plants or property or environment'. The Central Pollution Control Board (CPCB) had adopted first National Ambient Air Quality Standards (NAAQS) in 1982 to maintain the ambient air quality in India, as per the provision of the Air (Prevention and Control of Pollution) Act, 1981 and these standards have been revised by the CPCB in November 2009 as depicted in Annexure I. Therefore ambient air quality standard is developed as a policy guideline that regulates the effect of human activity upon the environment so that pollutant emission into the air can be regulated. Standards may specify a desired state or limit alterations.

Air pollutants whether man made or natural are to be monitored to know their characteristics and concentration in the ambient air. Monitoring helps us to take necessary preventive and control measures. Keeping this in view, Central Pollution Control Board initiated National Ambient Air Quality Monitoring (NAAQM) program in the year 1984 with 7 stations at Agra and Anpara. Subsequently the programme was renamed as National Air Quality Monitoring Programme (NAMP). The objectives of the NAMP are to determine status and trends of ambient air quality; ascertain whether the prescribed ambient air quality standards are violated; identify non-attainment cities where air pollutants are exceeded the prescribed standards; obtain the knowledge and understanding necessary for developing preventive and corrective measures and 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.

Steadily the air quality monitoring network got strengthened by increasing the number of monitoring stations from 28 to 365 during 1985 – 2009. During the financial year 2010 – 11, 93 new stations were added and the number of stations under operation was raised to 456 covering

190 cities in 26 states and 5 Union Territories as on 31st March 2011. As on 31st October 2011 the number of stations under operation has been further raised to 503 distributed in 209 cities, 26 states and 5 UTs *(CPCB, 2012).*

The growth in number of stations under operation is depicted in Figure 1.2.

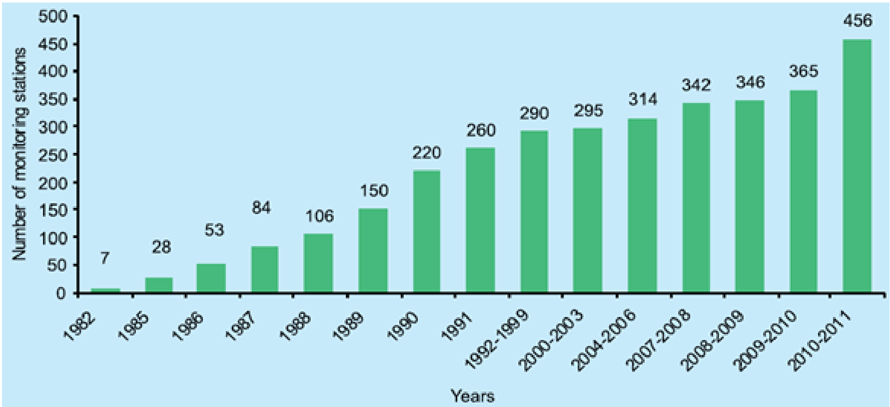

Figure 1.2 Growth in number of stations under operation in NAMP *(Source: CPCB, 2012)*

Under NAMP, four air pollutants, viz., sulphur dioxide (SO_2), oxides of nitrogen as (NO_X) and suspended particulate matter (SPM) and respirable suspended particulate matter (RSPM/PM10), are regularly monitored at all the locations. Besides this, additional parameters such as respirable lead and other toxic trace metals, hydrogen sulphide (H_2S), ammonia (NH_3) and polycyclic aromatic hydrocarbons (PAHs) are also being monitored in 10 metro-cities of the country since 1990. The Central Pollution Control Board collects the air quality data and brings out the annual air quality statistics. Based on such data, it has been possible to identify the polluted areas and also prepare action plans.

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

It is clear from the above classifications, that the locations in either of the first two categories are actually violating the standards, although, with varying magnitude. Those, falling in the third category are meeting the standards as of now but likely to violate the standards in future if pollution continues to increase and is not controlled. However, the locations in Low pollution category have a rather pristine air quality and such areas are to be maintained at low pollution level by way of adopting preventive and control measures of air pollution. The pollution control classification and annual average concentration in States and UTs of India are given in Table 1.2 and Figure 1.3 respectively.

Table 1.2 Pollution level classifications *(Source: CPCB, 2012)*

Pollution level	**Annual mean concentration range (µg/m3)**					
	Industrial, Rural, Residential & others areas			**Ecologically sensitive area**		
	SO_2	NO_2	PM_{10}	SO_2	NO_2	PM_{10}
Low(L)	0-25	0-20	0-30	0-10	0-15	0-30
Moderate(M)	26-50	21-40	31-60	11-20	16-30	31-60
High(H)	51-75	41-60	61-90	21-30	31-45	61-90
Critical(C)	>75	>60	>90	>30	>45	>90

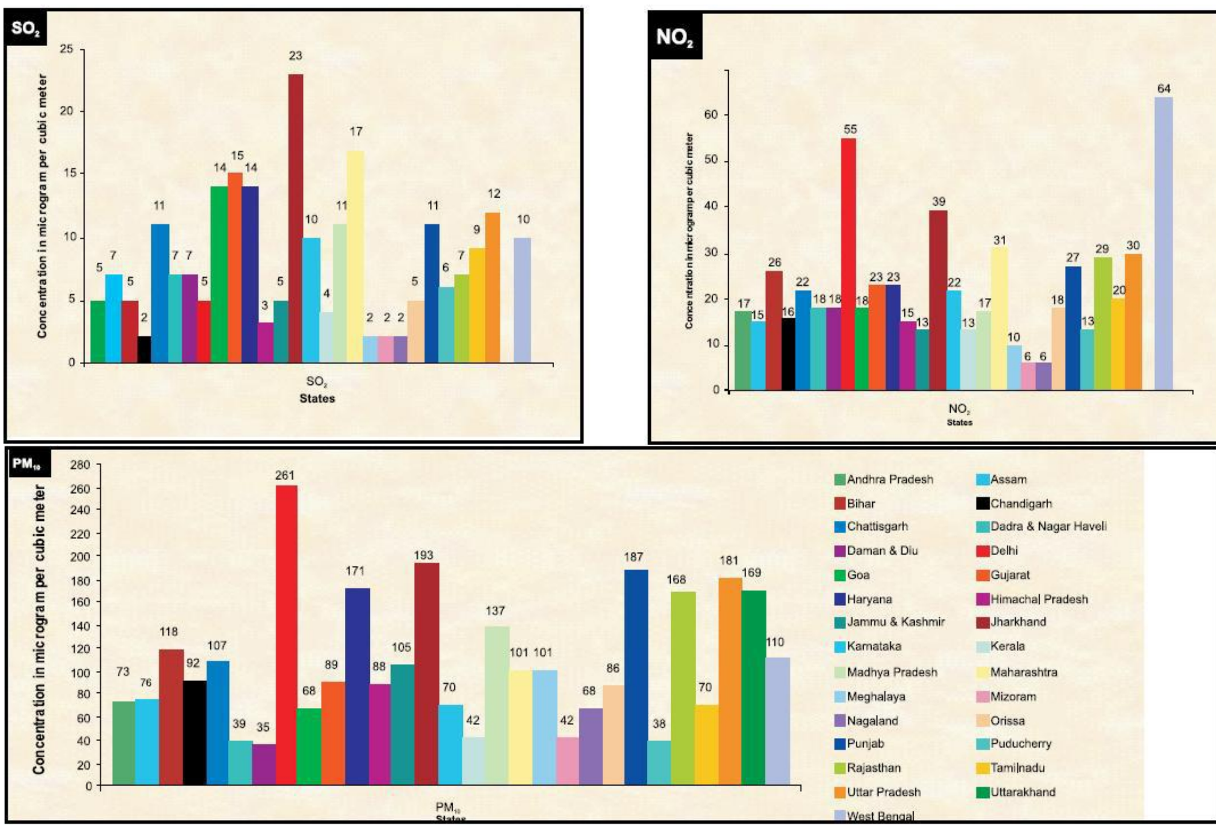

Figure 1.3 Annual average concentrations in States and UTs of India *(Source: CPCB, 2012)*

1.3 Thermal Power Plants

A thermal power station is a power plant in which the prime mover is steam driven. Water is heated, turns into steam and spins a steam turbine which drives an electrical generator. After it passes through the turbine, the steam is condensed in a condenser and recycled to where it was heated; based on Rankine cycle. The greatest variation in the design of thermal power stations is due to the different fossil fuel resources generally used to heat the water. Some prefer to use the term energy center because such facilities convert forms of heat energy into electrical energy. Certain thermal power plants are designed to produce heat energy for industrial purposes of district heating, or desalination of water, in addition to generating electrical power. The efficiency of a Rankine cycle is usually limited by the working fluid. Without the pressure reaching super critical levels for the working fluid, the temperature range the cycle can operate over is quite small: turbine entry temperatures are typically 565°C (the creep limit of stainless steel) and condenser temperatures are around 30°C. This gives a theoretical Carnot efficiency of about 63% compared with an actual efficiency of 42% for a modern coal-fired power station.

The power output or capacity of an electric plant can be expressed in units of megawatts electric (MWe). The electric efficiency of a conventional thermal power station, considered as saleable energy (in MWe) produced at the plant bus bars as a percent of the heating value of the fuel consumed, is typically 33% to 48% efficient.

1.3.1 Thermal Power Plant Status in India

Coal is the only natural resource and fossil fuel available in abundance in India. Consequently, it is used widely as a thermal energy source and also as fuel for thermal power plants producing electricity *(Mishra 2004)*. Power generation in India has increased manifold in the recent decades to meet the demand of the increasing population *(Jamil et al., 2009).* The installed capacity (Table 1.3) of thermal power plants (TPPs) in India as of August, 2011 stands at 118,409 megawatt (MW). Out of this, coal-based thermal power capacity contributes towards 84 per cent, gas-based thermal capacity is 15 per cent and diesel is one per cent. India has about 90,000 MWe installed capacity for electricity generation, of which more than 72% is produced by coal- based thermal power plants. The only fossil fuel available in abundance is coal, and hence its usage will keep growing for another 2–3 decades at least till nuclear power makes a significant contribution. The coal available in India is of poor quality, with very high ash content and low calorific value, and most of the coal mines are located in the eastern part of the country.

Table 1.3 Installed capacity of TPPs* in India *(Source: Centre of Science and Environment, 2012)*

	Installed capacity (in MW)
Coal	99503
Gas	17706
Diesel	1200
Total	**118409**

**As of August 2011*

Out of the 267 TPPs granted clearance in the 11th Five Year Plan (FYP), 200 are coal-based of 1.76 lakh MW installed capacity (Table 1.4). This is almost double the capacity of TPPs installed in the country presently.

Table 1.4 Year-wise environment clearance given to TPPs during the 11th FYP *(Source: Centre of Science and Environment, 2012)*

	2007	2008	2009	2010	Till Aug 2011	Total
Capacity (in MW)	55724	35558	35176	53598	29864	209919

1.3.2 Electricity production in Thermal Power Plants

The main process in a thermal power plant based on coal combustion is to convert chemical energy of coal to electrical energy. The main units of power plant are steam generator and turbine. Steam generator is the combination of heating surface in which superheated steam is generated with high pressure and temperature utilizing the heat liberated from combustion of coal. The steam so generated is fed into the turbine which converts the thermal energy of the steam into mechanical energy and drives the generator for producing electricity. Exhaust steam from the turbine is condensed and recycled to produce steam in steam generator. The condenser cooling is normally achieved by means of water in a closed cycle. The fuel is supplied into the boiler together with the combustion air Gaseous products of combustion are discharges into the atmosphere through the stacks. Bottom ash is disposed off by means of wet disposal system. The fly ash is arrested in electrostatic precipitators and disposed of in such a fashion that it can be utilized in dry form to the extent possible and unutilized fly ash is disposed of in ash disposal area.

The electrical energy generated is sent to the consumers through transmission and distribution network. Figure 1.4 presents general flow sheet for generation of electricity from coal.

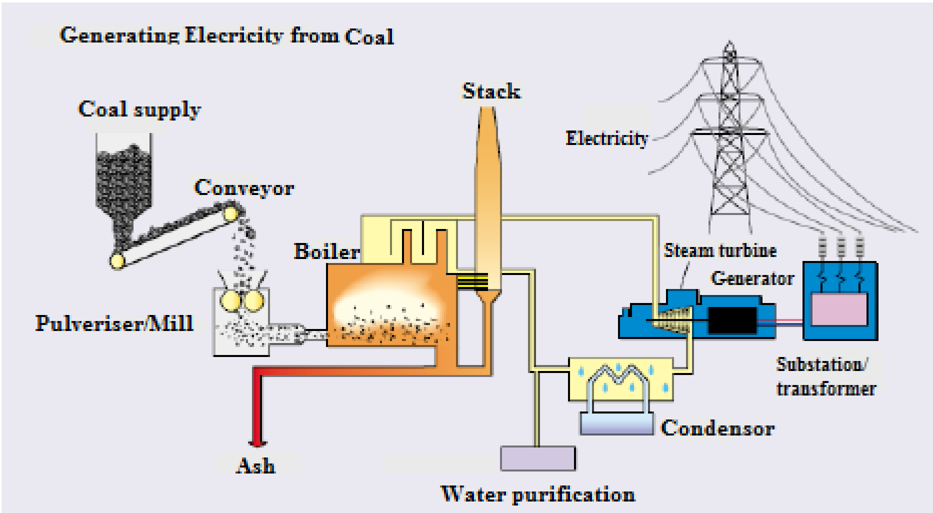

Figure 1.4: General process flow diagram for pulverized coal power plants *(Source: INTUSER, www. intuser.net)*

1.3.3 Supercritical Boiler Technology in Thermal Power Plant

"Supercritical" is a thermodynamic expression describing the state of a substance where there is no clear distinction between the liquid and the gaseous phase (i.e. they are a homogenous fluid). In boiler, when water reaches at a pressure above 221 bar up to an operating pressure of around 190 bar in the evaporator part of the boiler, the cycle is sub-critical. This means, that there is a non-homogeneous mixture of water and steam in the evaporator part of the boiler. In this case a drum-type boiler is used because the steam needs to be separated from water in the drum of the boiler before it is superheated and led into the turbine. Above an operating pressure of 221 bar in the evaporator part of the boiler, the cycle is supercritical. The cycle medium is a single phase fluid with homogeneous properties and there is no need to separate steam from water in a drum. The most obvious advantage of this technology is higher efficiency, and therefore, saving of fuel resources. The improvement in efficiency varies from 1.3% to 3.6% depending upon the steam parameters. Example, Capital cost for a supercritical power station shall be about 2% higher than that of sub-critical power plant but at the same time the plant efficiency shall improve from 38.64% to 39.6%.

1.3.4 Air Pollution by Thermal Power Plant

Thermal Power Plants (TPPs) have been found to affect adversely air quality of the surrounding region. Combustion process in TPPs converts coal into useful heat energy, but it is also a part of the process that produce greatest environmental and health concerns. Combustion of coal at thermal power plants emits mainly carbon dioxide (CO_2), sulphur oxides (SO_x), nitrogen oxides (NO_x); CFCs other trace gases and air borne inorganic particulates, such as fly ash and suspended particulate matter (SPM). CO_2, NO_x and CFCs are greenhouse gases (GHGs) High ash content in Indian coal and inefficient combustion technologies contribute to India's emission of air particulate matter and other trace gases.

Due to continuous & long lasting emission of SO_x & NO_x, which are the principal pollutants of coal based plants, surrounding structures, buildings, monuments of historic importance & metallic structures too are affected very badly due to corrosive (Acid rain) reactions. Well known example of this is the victimized Tajmahal of Agra which is being deteriorated due to these toxic gases. It is also worth to note that very high amount of carbon dioxide (CO_2) emission (0.9-0.95 kg/kwh) from thermal power plants contribute to global warming leading to climate change *(Pokale, 2012).*

Hence, there is a need to evaluate both qualitatively and quantitatively the pollutants generated from the thermal power plants into the atmosphere so that its harmful impacts can be anticipated and mitigation measures may be proposed accordingly.

CHAPTER 2

AIR QUALITY MODELLING

Air quality modeling is a mathematical tool used to predict and simulate the distribution and the behavior of air pollutants emitted to the atmosphere. It describes 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 pollution cannot be measured in every point for particular area because it requires a lot of money and time. Therefore, by the help of air pollution models, one can for example determine the suitable points for making pollution measurements. Air pollution models play an important role in science because of their capability to assess the relative importance of the relevant processes. Air pollution models are the only method that quantifies the deterministic relationship between emissions and concentrations/depositions, including the consequences of past and future scenarios and the determination of the effectiveness of abatement strategies. This makes air pollution models indispensable in regulatory, research, and forensic applications.

2.1 Air Quality Modelling

The purpose of these air pollution models is to quantitatively combine the effects of source strength and meteorology to describe the resulting ambient air pollution concentration. Source strength is affected by a number of variables including the size of the source, variable emission rates, and the efficiency of air pollution control equipment employed. Meteorology is affected by wind speed and direction, atmospheric stability, inversion height, and terrain features. Ambient air pollution concentrations occurring downwind of a source consist of two components:

pollution contributed directly by the source and the background pollution. Useful mathematical model must be able to account for all these parameters *(Miller and Noll, 1976).*

Most modern air pollution models are computer programs that calculate the pollutant concentration downwind of a source using information on the:

- contaminant emission rate
- characteristics of the emission source
- local topography
- meteorology of the area
- ambient or background concentrations of pollutant

A generic overview of how this information is used in a computer-based air pollution model is shown in Figure 2.1.

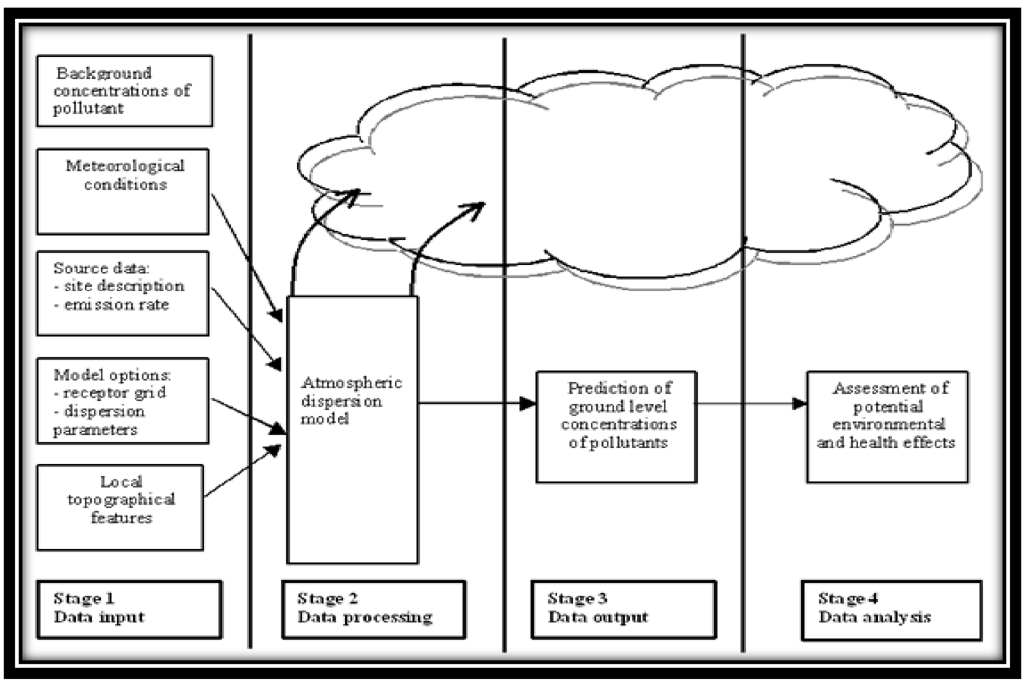

Figure 2.1 Overview of the air pollution modelling procedure *(Ministry of Environment of New Zealand, 2004)*

2.2 Classification of models

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

Steady-state models are models which assume no time-varying processes occur over the period of interest. Hence, material released travels infinitely in only one direction over the time period (e.g., one hour). Often, these models assume that the material is distributed normally (also termed a "Gaussian distribution") and are thus called "Gaussian plume" models. The steady-state model typically uses meteorological information obtained near the source and assumes it holds true throughout the modelling region (e.g., 50 kilometre radius). This type of model is most widely used for stationary sources and for non-reactive pollutants (although models can take into account deposition and simple linear decay). Examples of steady models are Screen 3, Industrial Source Complex Short Term Version 3 (ISCST3), American Meteorological Society/Environmental Protection Agency Regulatory MODel (AERMOD) and CALINE3.

Non-steady state models are models which can simulate the effects of time- and space varying meteorological conditions on pollutant transport, transformation, and removal. These models are often used for chemically reactive pollutants or where there is complex topography or meteorology (e.g., complex sea breeze circulation). They 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 models 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 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. Firstly, speciated data are required for source apportionment modeling; measurements of total mass for particles or total hydrocarbons are insufficient. Secondly, the species used in characterizing the sources either should not participate in atmospheric chemistry or should have very long lifetimes in the atmosphere. Examples of source-apportionment models are Chemical Mass Balance model (CMB), Unmix, Positive Matrix Factorization (PMF).

2.3 Selection of model

A model is a simplified picture of reality. It doesn't contain all the features of the real system but contains the features of interest for the management issue or scientific problem one wish to solve by its use. There are a wide range of models available, and it is important to select the model that meets the requirements of the task. No single model can handle all situations and range of applications. Models differ in the size of area that can be modelled and the number of situations that can be addressed. A model may be designed to handle only a single source, e.g., well test flare; multiple sources, e.g., a facility that has a flare stack, heaters and boilers; or combined sources, e.g., more than one facility and emission sources. The overall accuracy and precision of results determined by a model is generally proportional to the complexity of the model, which in turn affects input data requirements and overall resources.

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

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

2.4 Air dispersion modeling theory

Dispersion modeling uses mathematical equations describing the atmosphere, dispersion, chemical and physical processes influencing a pollutant released from sources of a given geometry to calculate concentrations at various receptors as a result of the release *(Holmes and Morawska, 2006)*. 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 the study area. The models then use this information to simulate mathematically the pollutant's transport and dispersion. The output is air pollutant concentrations, for a particular time period, usually at specific receptor locations.

2.4.1 Data required for dispersion modeling

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, modelling approach, and model selected for assessment can depend on the type of release being modelled.

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

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

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

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

– Release height above ground level (e.g., stack height, average height of fugitive emissions).

– Area of the release point (for point sources, stack diameter; for area sources, length and width of the area across which releases occur).

– Other stack parameters of the release stream for point sources that can alter the effective release height, which include temperature, stack orientation, the presence of obstructions to flow (i.e., rain caps), and exit velocity or flow rate. Flow rate is expressed in terms of the total volume of material released per unit of time.

– Facility building dimensions, if building downwash (i.e., the effects on plume dynamics due to structures located near the source) is modelled, provide concentration estimates at the nodes of the modelling 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 modelling 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 modelled, rates of transformation or removal for the chemicals being modelled are required.

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

2.4.2 Mechanisms of pollutants dispersion in the atmosphere

A simple example of pollutants dispersion in the atmosphere is through molecular diffusion, when 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 *(Cooper and Alley, 2002).*

Turbulence

Molecules of pollutants in the air are transported from one point to another by means of turbulence. Turbulence is defined as a collective random motion involving a group of many molecules. Turbulence is made up of both thermal and mechanical eddies. Eddies are macroscopic random fluctuations from the "average" flow and are responsible for the dispersion of pollutants in the atmosphere. Eddies disperse pollutants by intercepting the plume, replacing a batch of concentrated pollutants in a plume with a batch of clean air from a distance away from the plume, consequently diluting the plume and spreading it in both vertical and lateral directions *(Cooper and Alley, 2002).*

Mechanical turbulence

Mechanical turbulence is created through the interaction between the horizontal force exerted by one layer on an adjacent layer and the gradient of the mean velocity with height. The stronger the wind or the larger the roughness elements, the greater the mechanical turbulence, hence rough surfaces such as forests or trees produce more eddies than smooth surface such as ice. Buildings, trees and other obstacles increases mechanical turbulence because these obstacles increase the horizontal forces that slow down the mean wind *(Venkatram, 2008).* Plume dispersion can also be caused by random shift in the wind. Pollutant concentrations are measured over a certain period of time called averaging time, for example, an averaging time of an hour. The wind direction and speed change during this period and more or less pollutant is blown towards the receptor. As a result, these random fluctuations cause the spread of the plume over a large area downwind of the source *(Cooper and Alley, 2002)*. As the plume travels downwind of the source, the pollutant spreads further in the y and z directions, and the maximum concentration eventually decreases.

Thermal turbulence

The thermal energy generated from the sun is absorbed by the ground. The absorbed heat is transferred into the lower atmosphere by means of conduction and/or convection thus generating thermal eddies. More eddies are created when there is strong insolation than when the energy from the sun is weak *(Cooper and Alley, 2002).*

2.5 Dispersion models

Pollutants discharged into the air are transported over long distances by large scale air-flows and are dispersed by small-scale air-flows or turbulence, which mix pollutants with clean air. This dispersion by the wind is a very complex process due to the presence of different-sized eddies in atmospheric flow. Even under ideal conditions in a laboratory the dynamics of turbulence and turbulent diffusion are some of the most difficult in fluid mechanics to model. There is no complete theory that describes the relationship between ambient concentrations of air pollutants and the causative meteorological factors and processes *(Ministry of Environment of New Zealand, 2004).*

An atmospheric dispersion model is a:

- Mathematical simulation of the physics and chemistry governing the transport, dispersion and transformation of pollutants in the atmosphere
- Means of estimating downwind air pollution concentrations for given information about the pollutant emissions and nature of the atmosphere processes *(Ministry of Environment of New Zealand, 2004).*

Atmospheric dispersion models use mathematical and numerical techniques 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 *(Schnelle and Brown, 2002).*

The dispersion models used in the study were:

- Industrial Source Complex Short Term Version 3 (ISCST3)
- AERMOD (**A**merican Meteorological Society/**E**nvironmental Protection Agency **R**egulatory **MOD**el)

2.5.1 Gaussian Plume Model

Gaussian type models are the most common dispersion models used in atmospheric dispersion modeling. The Gaussian-plume formula is derived assuming ‘steady-state’ conditions. That is, the Gaussian-plume dispersion formula does not depend on time, although they do represent an ensemble time average. This type of model assumes that the pollutant disperses according to the normal statistical distribution *(Holmes and Morawska, 2006).* At the point of release, the pollutant concentration is at maximum and decreases in both lateral and vertical directions following the normal distribution. The two models used in this comparative study were developed based on Gaussian plume.

The Gaussian model uses a Gaussian equation which is used for point source emissions in general *(Cooper and Alley, 2002):*

$$C(x, y, z) = \frac{Q}{2\pi u \sigma_y \sigma_z} \times \left[\exp - \left(\frac{y^2}{2\sigma^2_y} \right) \right] \left\{ \exp\left(\frac{-(z-H)^2}{2\sigma^2_z} \right) + \exp\left(\frac{-(z+H)^2}{2\sigma^2_z} \right) \right\} \quad \ldots(2.5)$$

Where:

C = steady-state concentration at a point (x, y, z), μg/m3

Q = pollutant emission rate, μg/s

U = mean wind speed at release height

σ_y σ_z = standard deviation of lateral and vertical spread parameters

y = horizontal distance from plume centerline, m

H = effective stack height (H = h +Δh) where h = physical stack height and Δh = plume rise,

z = vertical distance from ground level, m

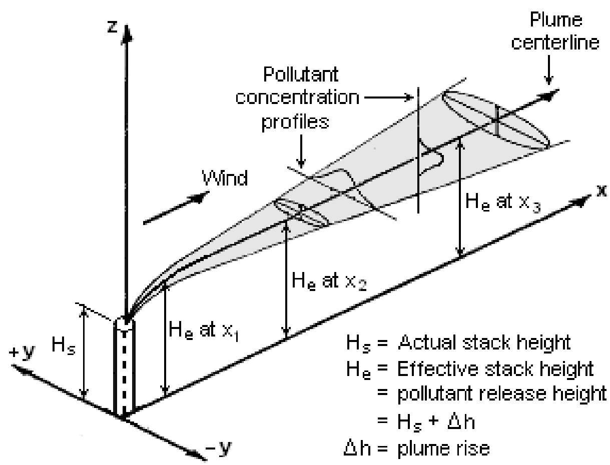

Figure 2.2 Graphical representation of double Gaussian distribution in the plume *(Vannucci et al, 2008)*

The first exponential term represents the lateral dispersion and vertical dispersion is described by the second exponential term. The terms σ_y and σ_z in equation 2.5 represent the standard deviation of the horizontal and vertical distributions of the plume of the pollutant. In older models, these coefficients are defined by stability classes created by Pasquill and Gifford and they increase as the downwind distance increases *(Holmes and Morawska, 2006).* The Gaussian model is based on the following assumption: the emission must be constant and uniform; the wind direction and speed are constant; net downwind diffusion is negligible compared to vertical and crosswind diffusion; the terrain is relatively flat; there is no deposition or absorption of the pollutant and the vertical and crosswind diffusion of the pollutant follow a Gaussian distribution *(Reed, 2005)*. Gaussian plume models have a limitation when they are applied to particle dispersion modelling. This limitation is a result of the use of steady state approximations without taking into account the time required for the pollutant to travel to the receptor and the vertical particle movement due to gravity during this time *(Holmes and Morawska, 2006).* However, in recent years, advanced Gaussian models have been developed that overcome most of the limitations in Gaussian models developed earlier.

2.5.2 Industrial Source Complex Short Term Version 3

ISCST3 is a short range (~50 km) dispersion model was developed by U.S. EPA in 1995. It is the most widely used model. It is a steady-state Gaussian plume model which is used with some modifications to model various kinds of sources, e.g., simple point source emissions from stacks, multiple vents, storage piles, conveyor belts, and the like. Therefore, the parameters such as meteorological conditions and emissions rate were kept constant through the calculations.

PC-RAMMET is a meteorological pre-processor for ISCST3 model. For ISCST3, the minimum input data requirements to the PC-RAMMET are the twice-daily mixing heights and hourly surface observations of wind speed, wind direction, dry bulb temperature, opaque cloud cover and ceiling height. The operations performed by the PC-RAMMET include: 1) calculation of hourly values for atmospheric stability from meteorological surface observations; and, 2) interpolation of twice-daily-mixing heights to hourly values. Thus, ISCST3 model estimates the concentration or deposition value for each source and receptor combination for each hour of input meteorology, and calculates user-selected short-term averages.

2.5.3 AERMOD

AERMOD was developed for regulatory purposes in 1991 by AERMIC- American Meteorological Society (AMS)/USEPA Regulatory Model Improvement Committee. It is also a steady-state Gaussian plume model for a short range (~50km) that incorporates air dispersion based on planetary boundary layer (PBL) turbulence structure and scaling concepts. It includes treatment of both surface and elevated sources and both simple and complex terrain *(EPA, 2004)*. It is applicable to rural and urban areas, and multiple sources including point, area, and volume sources *(Vora, 2010).* AERMOD contains improved algorithms for: dispersion under stable and unstable conditions; plume rise and buoyancy; plume penetration into elevated inversions; treatment of elevated, near-surface, and surface level sources; computation of vertical profiles of wind, turbulence, temperature and terrain effects on plume behavior. AERMOD also includes the PRIME building downwash algorithms.

The concentration distribution in the stable boundary layer (SBL) is assumed to be Gaussian in both vertical and horizontal planes. The American Meteorological society (AMS) defines SBL as a cool layer of air adjacent to a cold surface of the earth, where temperature within that layer is statically stably stratified. In convective boundary layer (CBL), the horizontal distribution is assumed to be Gaussian while the vertical distribution is described with bi-Gaussian probability density function *(Cimorelli et al, 2004).* AMS defines CBL as a type of atmospheric boundary layer characterized by vigorous turbulence tending to stir and uniformly mix, primarily in the vertical, quantities such as conservative tracer concentrations, potential temperature and momentum or wind speed.

AERMOD modelling system comprises a meteorological pre-processor (AERMET), a terrain pre-processor (AERMAP) and the dispersion model (AERMOD). The flow and processing of information in AERMOD has been presented in Figure 2.3.

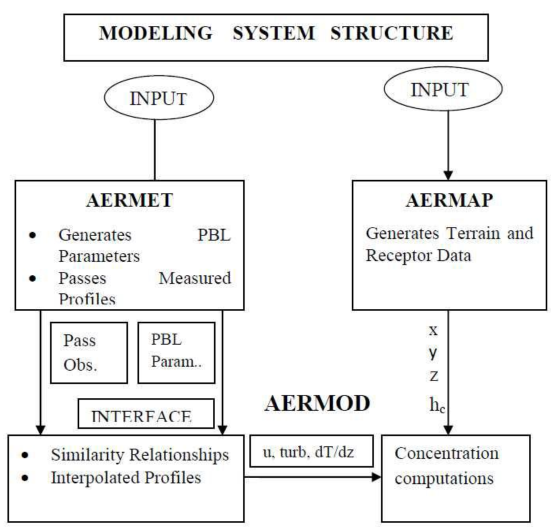

Figure 2.3 The flow and processing of information in AERMOD *(US EPA 2003)*

AERMET provides AERMOD with the meteorological information needed to characterize the PBL. AERMET requires standard meteorological observations such as wind speed, wind direction, temperature and cloud cover. It also needs the surface characteristics parameters of albedo, surface roughness and Bowen ratio. It then makes use of this data for the calculations of planetary boundary layer (PBL) parameters such as: Mixing height (z), Monin – Obukhov length (L), temperature scale, convective velocity scale (w) and surface heat flux (H) *(Cimorelli et al., 2004).* The information from AERMET is passed on to AERMOD where similarity theories are used to calculate lateral and vertical turbulent fluctuations (v, w), vertical profiles of wind speed (u) and potential temperature gradient (dθ/dz).

AERMAP is used to calculate the terrain height scale (hc) for each receptor location, which is used to calculate the dividing streamline height. AERMAP also generates receptor grids for AERMOD. The input to AERMAP is the topographical data in a format of Digital Elevation Mapping (DEM) files. The information generated from AERMAP is then passed on to AERMOD as the location of receptors, the receptor's height above mean sea level and the receptor specific terrain height scale (hc) *(Cimorelli et al., 2004).*

AERMOD then uses this information from the two pre-processors to compute concentrations of pollutants, taking into account the changes in dispersion rate with height and making use of non-Gaussian plume in convective conditions.

2.5.4 Comparison of ISCST3 and AERMOD

Both models (ISCST3 and AERMOD) are regulatory models. It is not possible to modify or make changes in the algorithms of the models. ISCST3 and AERMOD generate different results in the same circumstances. AERMOD use new or improved algorithms in its calculation when compared to ISCST3. It takes more meteorological data into account, and analyzes the effect of factors such as the type of terrain and land use. ISCST3 contains several outdated concepts and practices, such as the simplified dispersion scheme based on the Pasquill-Gifford-Turner approach to characterize atmospheric turbulence using stability classes which was initially developed for rural low-level sources and does not always lead to reasonable predictions for all source types and locations. A key difference between the two models is the replacement of the Pasquill-Gifford- Turner system with the use of Planetary Boundary Layer (PBL) and similarity theory to determine dispersion coefficients. The Planetary Boundary Layer is the lowest portion of the atmosphere where the pollutants are emitted, transported, mixed, dispersed and a general term used to describe the turbulent air layer next to the earth's surface that is controlled primarily by surface heating and friction. The Planetary Boundary Layer typically ranges from a few hundred meters in depth at night to 1 - 2 kilometers during the day (*TCEQ, 2003*).

AERMOD makes use of the surface characteristics such as albedo, bowen ratio, and surface roughness to generate more realistic estimates which is not applicable in ISCST3.

Table 2.1 provides a more extensive list of the comparison features between AERMOD and ISCST3 *(U.S. EPA, 2003).*

Table 2.1 Comparison features between AERMOD and ISCST3 model *(U.S. EPA, 2003)*

Feature	**ISCST3**	**AERMOD**	**Comments**
Types of sources Modeled	Point, area, and volume sources	Same as ISCST3	Models are Comparable
Plume Rise	Uses Briggs equations with stack-top wind speed and vertical temperature gradient	In stable conditions, uses Briggs equations with winds and temperature gradient at stack top and half- way to final plume rise; in convective conditions, plume rise is superposed on the displacements by random convective velocities	AERMOD is better because in stable conditions it factors in wind and temperature changes above stack top, and in unstable conditions it accounts for convective updrafts and downdrafts
Meteorological Data Input	One level of data accepted	An arbitrarily large number of data levels can be accommodated	AERMOD can adapt multiple levels of data to various stack and plume heights
Profiling Meteorological Data	Only wind speed is profiled	AERMOD creates profiles of wind, temperature, and turbulence, using all available measurement levels	AERMOD is much improved over ISCST3 in this area
Plume Dispersion: General Treatment	Gaussian treatment in horizontal and vertical	Gaussian treatment in horizontal and in vertical for stable conditions; non-Gaussian probability density function in vertical for unstable conditions	AERMOD's unstable treatment of vertical dispersion is a more accurate portrayal of actual conditions
Characterization of Modeling Domain Surface Characteristics	Choice of rural or urban	Selection by direction and month of roughness length, albedo, and Bowen ratio, providing user flexibility to vary surface characteristics	AERMOD provides the user with considerably more options in the selection of the surface Characteristics

Boundary Layer Parameters	Wind speed, mixing height, and stability class	Friction velocity, Monin-Obukhov length, convective velocity scale, mechanical and convective mixing height, sensible heat flux	AERMOD provides parameters required for use with up-to-date planetary boundary layer (PBL) parameterizations; ISCST3 does not
Terrain Depiction	Elevation at each receptor point	Controlling hill elevation and point elevation at each receptor, obtained from special terrain pre-processor (AERMAP) that uses digital elevation model (DEM) data	AERMOD's terrain pre-processor provides information for advanced critical dividing streamline height algorithms and uses digital data to obtain receptor elevations
Plume Interaction With Mixing Lid: Convective conditions	If plume centerline is above lid, a zero ground level concentration is assumed	Three plume components are considered: a "direct" plume that is advected to the ground in a downdraft, an "indirect" plume caught in an updraft that reaches the lid and eventually is brought to the ground, and a plume that penetrates the mixing lid and disperses more slowly in the stable layer aloft (and which can re-enter the mixed layer and disperse to the ground)	The AERMOD treatment avoids potential under predictions suffered by ISCST3 due to its "all or nothing" treatment of the plume; AERMOD's use of convective updrafts and downdrafts in a probability density function approach is a significant advancement over ISCST3
Plume Interaction With Mixing Lid: Stable conditions	The mixing lid is Ignored (assumed to be infinitely high)	A mechanically mixed layer near the ground is considered. Plume reflection from an elevated lid is considered.	AERMOD's use of a mechanically mixed layer is an advancement over the very simplistic ISCST3 approach

2.6 Validation of Model

A model is a simplified picture of reality. 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. Because different models are likely to produce different results under different conditions, it would be interesting to evaluate and validate the nature and magnitude of these differences. Policy-makers will look to see if models have been verified or validated. The differences between evaluation and verification or validation are important, particularly in the context of air quality modelling. Full model evaluation and validation include a thorough peer review of the science of the model; evaluation of the model's ability to predict concentrations of the pollutant of interest by comparing predictions against measurements; comparison of the performance of two or more models; more detailed evaluation of the ability of the model to predict correctly the concentrations of other chemical species involved in the chemical scheme. 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

The science of “atmospheric dispersion modelling” is recognized to have started in the 1950s but real efforts began after 1917. 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 modelling in December, 1977. The Air Pollution Control Association (APCA) presented a Critical Review on “Atmospheric Dispersion Modelling” at the 1979 Annual Meeting and subsequently published a critical review as an APCA Reprint Series (Volume 10) in March, 1980.

Atmospheric (Air) dispersion models are indispensable tools for assessing the impact of air pollutants on human health and the urban environment. EPA began such a process when the American Meteorological Society/Environmental Protection Agency Regulatory Model Improvement Committee (AERMIC) met in 1999 to introduce state-of-the art modelling concepts into EPA’s air quality models. The new AERMIC Dispersion Model, known as AERMOD, was phased in during the year 2000 replacing the ISC standard regulator model. Air quality protection is a key element in ensuring sustainable livelihoods for both present and future generations. Literature abounds in studies on air quality modelling and the effect of industrial emissions on ambient air quality. Below is presented a selection of works that have dealt with the topic and also the main inferences that emerge from these studies both at national and international levels.

3.1 INTERNATIONAL SCENARIO

The study conducted by *Toro et al., (1998)* presented the potential dispersion modelling uses of archived National Oceanic and Atmospheric Administration (NOAA) forecast model data. This newly developed generation of air quality simulation models has the potential to use wind profiles, temperature and turbulence as well as improved mixing height determination measures of surface heat flux and host of other meteorological parameters. *Basham et al., (1999)* used the ISCST3 model to estimate toxic equivalent ground level concentration of dioxins emitted from the Avonmouth municipal waste incinerator in Bristol, UK. The sensitivity of the predicted ground level concentration to various vapour and particle partitioning scenarios was reported.

They reported that the use of local terrain and emission data in municipal waste incinerator dispersion modelling was crucial for health risk assessments associated with human dioxin intake, especially in view of the debate over the tolerable daily intake for dioxins.

Dabberdt et al., (2000) addressed modelling issues related to accidental chemical releases. The application to emergency response dispersion modelling was illustrated using an actual event that involved the accidental release of the toxic chemical oleum. *Hassid et al., (2000)* described their experience in using US EPA Gaussian models for developing environmental impact statements that focused on four different sectors: highway, quarries, airports, and tunnels. *Koracin et al., (2000)* performed a comprehensive modelling study of PM-10 impact in Treasure Valley, Idhao. The ISCST3 model, using as input base year meteorology and gridded emissions for mobile sources, point sources and wood burning, generally agreed well with measurements in both temporal patterns and annual averages. *Ashok et al., (2006)* used AERMOD dispersion model to compute ambient air concentrations of SO_2 for 1-, 3-, and 24-h averaging periods using the emission inventory data for Lucas County, Ohio for the year 1990. The data were divided into two atmospheric stability classes (stable and convective cases) as used in the AERMOD model. AERMOD did not yield a satisfactory performance in predicting 1- and 3-h average concentrations for the multisource region but showed a slightly better performance in predicting the 24-h concentrations using urban option for the land use parameters.

Comparing modelled pollutant concentrations predicted by AERMOD with observed concentration, *Schewe et al., (2003)* 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.

Kumar et al., (2006) also observed that model prediction was below observed concentrations but became better as the length of the averaging period increased from observations made in an urban area of Lucas County, Ohio, United States. *Ding, (2012)* applied AERMOD model to simulate the pollutant concentration at different heights in Beilun District, China and the results showed that the ground daily average concentration of SO_2 was equivalent to 26.7%~53.3% of ambient air quality standard, and the concentration of NO_2 was equivalent to 16.7%~58.3% but the concentration of SO_2 and NO_2 was relatively higher in the upper air of Beilum district.

Kasemsan et al., (2012) reported a dispersion study of NO_2 and SO_2 using the AERMOD model in Map Ta Phut industrial area (MA), Thailand. For the year 2010 the area specific emission inventories of NO_2 and SO_2 were prepared, including both stack and non stack sources, and divided into 11 emission groups. Underestimation of both pollutants was found, and stack emission estimates were scaled to improve the modelled results. Two concentration measures (i.e., annual average area-wide concentration or AC, and area-wide robust highest concentration or AR) of SO_2 and NO_2 were used to aggregately represent mean and high-end concentrations for four selected impact areas. For AC-NO_2, on-road mobile emissions were found to be the largest contributor in the two residential areas (36–38% of total AC-NO_2), while petrochemical-industry emissions play the most important role in the two industrialized areas (34–51%). For AR-NO_2, biomass burning has the most influence in all impacted areas (>90%) except for one residential area where on-road mobile is the largest (75%). For AC-SO_2, the petrochemical industry contributes most in all impacted areas (38–56%). For AR-SO_2, the results vary.

Honghong et al., (2013) studied the influence of emission control policy (emission reduction targets in the national "12th 5 years" plan) on the air quality in the near future over an important industrial city of China, Xuanwei in Yunnan province, by applying the AERMOD for evaluating the simulation results of SO_x, and NO_x in 2008 and 2015. Results in spatial allocation shows that reduction effect of SO_2 is more significant than NO_X in 2015 as the contribution of SO_2 from industry is more than NO_X.

Demirarslan et al., (2013) studied the evaluation of CO and NO_x distributions emitted to the atmosphere from point sources in Körfez District of Kocaeli Province. For this , CO emissions emitted from 20 factory chimneys and NO_x emissions emitted from 15 factory chimneys were modelled and the daily and annual distribution maps were obtained. The modelling study showed that the maximum ground-level CO concentrations were calculated as 335.24μg/m^3 and 70.02μg/m^3 in daily and annual basis respectively. On the other hand, for NO_x concentrations, daily and annual maximum values were calculated as 372.05μg/m^3 and 26.29μg/m^3 respectively.

Several investigations have been conducted to determine the differences in predicted pollutant concentrations on the basis of AERMOD and ISCST3 model runs. *Long et al., (2004)* compared 1-hr and 24-hr modelled concentrations of pollutants from multiple source types in the San Francisco Bay area and found that, AERMOD predicted consistently lower pollutant concentrations when compared to ISCST3, except for 1-hr concentrations. Similar study was done by *Faulkner et al., (2008)* in the San Francisco Bay area and determined the sensitivity of AERMOD to various inputs and compare the highest downwind concentrations from a ground-level area source (GLAS) predicted by AERMOD to those predicted by ISCST3. 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, whereas AERMOD was sensitive to changes in albedo, surface roughness, wind speed, temperature, and cloud cover.

Comparing the performance of ISCST3 and AERMOD in a complex terrain scenario and a flat terrain scenario with multiple point, area, and volume sources, *Tarde and Westbrook., (2003)* found that AERMOD predicted higher 24-hr concentrations of PM_{10} in flat areas but lower concentrations than ISCST3 in complex terrain. *Morrison (1998)* found opposite results with ISCST3 predicting higher 24-hr concentrations than AERMOD in flat terrain with abrupt land-use changes and AERMOD predicting higher 24-hr concentrations in intermediate complex terrain. It was reported that ISCST3 predicted much higher 1-hr concentrations than AERMOD in complex terrain, but the models predicted similar 1-hr concentrations in the flat terrain scenario. In general, AERMOD seems to perform better in complex terrain than does ISCST3.

Silverman et al., (2007) compares the ISCST3 and AERMOD dispersion models as well as their enhanced versions that incorporate the Plume Rise Model Enhancements (PRIME) algorithm for Human Health Risk Assessment. PRIME takes into account the effects of building downwash on plume dispersion. The results show that the 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 types of the sources and the site-specific conditions.

Perry et al., (2011) compared several existing air dispersion models in terms of modelled and observed concentration distributions and concluded that with few exceptions the performance of AERMOD is superior to that of the other applied models. TSP and PM10 was modelled in ISCST3 and AERMOD using meteorological data by *Jose et al., 2012***.** Data was collected by 3 local stations in Northern Colombia during 2008 and 2009. High correlation coefficients (>0.73) were obtained with monitored data. Models then forecast the PM concentration and resulted in highly, fairly, moderately and marginally polluted according to local regulations leads to relocation of 3 villages.

3.2 NATIONAL SCENARIO

Several studies have been conducted using ISCST3 and AERMOD dispersion model for predicting the air quality in India. *Sivacoumar et al., (2000)* estimated the impact of NO_x due to various air pollution sources using ISCST3 Gaussian dispersion model at Jamshedpur. Further statistical analysis was carried out to evaluate the model performance by comparing measured and predicted NO_x concentrations, wherein, the model performance was found good with an accuracy of about 68%. Similarly, *Bhanarkar et al. (2005)* estimated the contribution of pollution (SO_2 and NO_2) using ISCST3 model from various sources in Jamshedpur, one of the steel cities of India, in winter 1993 using two approaches in order to delineate and prioritize air quality management strategies for the development of region in an environmental friendly manner. The analysis indicated that emissions from industrial sources were responsible for 50% of the total SO_2 and NO_2 concentration levels.

Atli (2002) investigated the effects of Adana Cement Factory place on air quality in the region with a focus on the ground level concentrations of PM_{10}, NO_x, CO and SO_2 on a 20 km by 20 km study area. *Reddy et al., (2005)* had used the ISCST3 model to study the impact of an industrial complex, located at Jeedimetla in the outskirts of Hyderabad city, India, on the ambient air quality with special reference to SO_2. The 8- and 24-h averaged model-predicted concentrations have been compared with corresponding observed concentrations and the results showed that the model-predicted concentrations were in good agreement with observed values and the model performance was found to be satisfactory. *Sharma and Chandra (2008)* reported a detailed scenario analysis of Kanpur city of India using the ISCST3 model to estimate the changes in emissions (SPM) that would take place due to various interventions. The model predicted values for the scenario without intervention yielded in an underestimation of 48% that was attributed to unaccountable or unidentified sources, trans-boundary movement of suspended particulate matter and model calibration errors. Thus the model was calibrated with the observed values in order to overcome the errors and results were obtained for other scenarios using the calibration factor. *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%) 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.

Venketa S., (2009) used Emission factors (EFs) for regulated PM_{10} and $PM_{2.5}$ in conjunction with dispersion models to predict 24-hour concentrations that were compared to National Ambient Air Quality Standards (NAAQS) for determining the required control systems in permitting sources. Measured concentrations of TSP and PM10 along with meteorological data were used in conjunction with the dispersion models ISCST3 and AERMOD, to determine the emission fluxes from cotton harvesting. From the comparison between AERMOD and ISCST3, it was observed that AERMOD EFs were 1.8 times higher than ISCST3 EFs for a six-row harvester. This suggests that EFs for fugitive emissions developed using dispersion models are model specific. *Sudarsan et al., (2010)* studied the role of weather data in validating air quality models for rural area near by Chennai. Local meteorological data have been used to a greater accuracy to validate the models AERMOD and ISCST3 for the point source of emission of SO_2. Results showed that both AERMOD and ISCST3 have under predicted the concentrations than that of the observed value and the accuracy of the predicated data is mainly depending on the weather data. *Banerjee et al., (2011)* performed the source-contribution assessment of ambient NO_2 concentration at Pantnagar, India through simulation of two urban mathematical dispersive models namely Gaussian Finite Line Source Model (GFLSM) and Industrial Source Complex Model (ISCST-3) and model performances were evaluated. Both GFLSM and ISCST-3 were simulated in conjunction with developed emission inventories and existing meteorological conditions and results indicated that contribution of NO_2 from industrial and vehicular source was in a range of 45–70% and 9–39%, respectively.

Namdeo et al., (2012) reported on the applicability and performance of some well known air quality dispersion models like AERMOD and ISCST3 models for Indian conditions. The evaluation of these models has been carried out in Delhi, India using the historical air quality, meteorological and traffic data for the year 2007. Model performance was in generally adequate for NO_2 and CO, but not for $PM_{2.5}$. It was advised that air quality modellers in India acquire data that is representative of the study domain before informing policy makers of their findings.

3.3 RESEARCH GAPS

Air quality in urban areas can be determined either monitoring or by prediction models. Monitoring provides data on actual existing condition, but practically and economically it is not possible to monitor at every location of interest to get spatial and temporal mapping. Also it does not support prediction of future state. Further, emission inventories were reported for rare areas leads to difficulty in compiling the input data for modelling. There is no robust structure or a platform for the air quality work to participate and share research, education and practices. From the detailed literature review mentioned above, it is evident that few reports highlight the air quality of critically polluted industrial areas in India but still study is incomplete and partial in comparison to global scenario. As, power generation through Thermal Power Plants in India has increased manifold in the recent decades to meet the demand of the increasing population. Further, no detailed study of the prediction of ground level concentrations at sensitive receptors using dispersion modelling has been published related to Thermal Power Plants in India. Moreover, comparison of outcomes from different air quality dispersion models needs to explore.

3.4 OBJECTIVES

Keeping in view the technological gaps in the literature on this aspect, the present study aims at the following key objectives:

1. To prepare an emission inventory for SO_2, NO_2 and SPM from a prevailing sources of a thermal power plant.
2. Use of ISCST3 and AERMOD modelling techniques for predicting the ground level concentration of pollutants at different receptors and its comparison.
3. Validation of the models with the existing air quality within 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 ISCST3) and procedures used for stacks sampling and analysis of pollutant concentrations at different receptor points.

4.1 Chemicals Used

Chemicals used for the analysis are Barium chloride, assay of 99%, Sodium hydroxide, assay of 98%, Sodium arsenite, assay of 98-102%, Potassium chloride, assay of 98%, Mercuric chloride, assay of 99.5%, EDTA, assay of 99%, Sulphanilamide, assay of 99%, N-(1-Naphthyl)-ethylenediamine Di-hydrochloride (NEDA), assay of 99%, Hydrogen peroxide, assay of 29-32%, Sulphamic acid, assay of 99%, Formaldehyde, assay of 37-41%, Sodium metabisulphite, assay of 96.5-100%, Sodium sulphite, assay of 96%, Para rosaniline, assay of 95%, Hydrochloric acid, assay of 35-38% and Sodium nitrite, assay of 98%. All the chemicals used were acquired from Loba Chemie Company.

4.2 Instruments Used

4.2.1 High Volume Sampler with gaseous attachment

High Volume Sampler is the basic instrument used to monitor ambient air quality. In this study, Envirotech APM 415 with its attachment for gaseous pollutant monitoring APM 411 was used with flow rate of 1.1 – 1.7 m^3min^{-1} and the filter paper used was Whatman 934-AH Glass Microfiber Filter which retains the particles. The instrument measures the volume of air sampled, while the amount of particulates collected is determined by measuring the change in weight of the filter paper as a consequence of the sampling. In High Volume Sampler provisions have been made for simultaneous sampling of gaseous pollutants. Gaseous attachment contains three impinger bottles of 35ml capacity for simultaneous absorption of different gaseous pollutants.

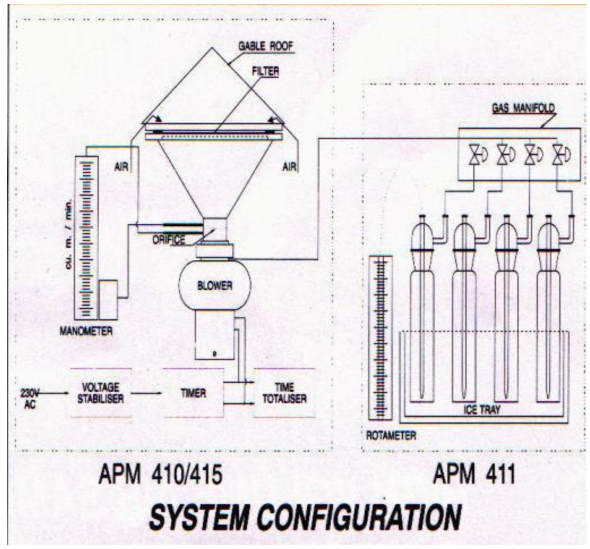

Fig 4.1: High Volume Sampler APM 415 **Fig 4.2**: System Configuration of gaseous extension with HVS

4.2.2 Weather Monitoring Station (WMS)

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

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

Figure 4.3: Weather monitoring station

4.2.3 Stack Monitoring Kit

Spectro's Stack Sampler SLE-ss115 was used to monitor SPM and gaseous pollutants from stack or chimneys emission. Collection is based on wet chemical techniques and it measures total quantity/volume of emissions. For particulate sampling, Whatman Glass Micro Fibre Thimbles sizes 19 x 90mm were used with maximum operating temperature of up to 500˚C. Its measurement ranges are temperature: ambient to 600˚C; velocity: 0-60m/s; for particulate sampling, flow rate: 0-30 LPM; filter range few milligrams to 100g/m^3; and for gaseous sampling, flow rate: 0-3 LPM and range from few micrograms to 100mg/m^3 depending upon analytical method used. Some of the important components of kit are thermocouple, pitot tube, nozzles, filter holder, sampling probe, inter connection tubing, vacuum pump assembly and sampling train for impingers.

Figure 4.4: Stack monitoring kit

4.2.4 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 0.1 nm. Spectrophotometer is having both Tungsten and Deuterium lamp at operating temperature of 0-40^{o}C.

4.3 Methodology

The study was carried out in three steps which are:

- Site selection and study area
- Selection of stack sampling site and receptor points
- Meteorological monitoring
- Source emission inventory
- Use of ISCST3 and AERMOD for modeling
- Air Quality Monitoring and Analysis
- Validation of ISCST3 and AERMOD model

4.3.1 Description of site and study area

Thermal Power Plant commissioned by Nabha Power Limited located near Nalash village and about 8km from Rajpura town is the site for this study. Nabha Power Limited (NPL), a wholly owned company of Punjab state electricity Board (PSEB) and Government of Punjab established 1400 MW Coal based Thermal Power Plant on Build, Own and Operate (BOO) basis. The power plant is constructed and operated by the Larsen & Toubro. The latitude and longitude of proposed site are 30° 32’ 36’’ to 30° 33’ 51’’ N and 76° 33’ 42’’ to 76° 35’ 05’’ E. The general elevation of plant site is 271 m high above sea level and the estimated land acquisition of plant is about 1080 acres. The location of the power plant and geographical characteristics of the study area are shown in Figure 4.5. A general view of the power plant is seen in Figure 4.6.

The plant comprises of two unit of 700 MW each with super-critical parameters for the steam generator and steam turbine using state of the art super-critical boiler technology used for steam generation. The output electricity production from single unit was 700 MW that commenced on December 8, 2013. Plant consumes 18,600 tonne/day of coal from SECL coal fields of State of Orissa located about 1400km from the site. The coal for the plant is brought from the coal mines by Indian railway system. The water requirement for the plant is about 3550m^3/hr which is met from Rajpura distributory of Bhakra main canal at a distance of about 1km. It is the first efficiently working super-critical thermal power plant in Punjab. It uses the pulverized coal combustion technology. Both the units are equipped with Electrostatic Precipitators (ESP). The nearest city to the thermal power plant is Rajpura.

Rajpura is an important subdivision / tehsil of Patiala district of Punjab which is situated 8 km from thermal power plant. According to 2011 India census, Rajpura had a population of 96,659, but after including some villages like Dhamoli kalan, Islampur, Neelpur, and Pilkhani, within its municipal limits the population rose to 112,193. Rajpura is an industrial town. There are number of large-scale industries like HUL (Formerly known as HLL), Amrit Vanaspati Pvt. Ltd, Siel Chemicals Limited, Amber Enterpsises Limited, Sahni Chemicals and there are large number of small scale industries. In small scale industries, Rajpura is a hub of Door Closer, Rice Sheller, Biomass Briquette Machinery, Soap Factories, House Hold Manufacturers, Biscuit machines industry and steel works. The total area under industry within Rajpura comprising of all industries is 903.44 Ha. Table 4.1 shows the major industrial area in M.C. and L.P.A Rajpura. Mainly the small scale industries are located in the focal point.

Table 4.1 Major Industrial Areas in M.C. and L.P.A Rajpura (*Source: P.R.S.C. Ludhiana)*

S.No.	Name of industry	Location	Area (in acres)
1.	Industrial focal point	Rajpura-Chandigarh road	149.68
2.	Industrial Estate	I.T.I.Road	14.00
3.	Mukat Pipe	Patiala- Rajpura road	6.20
4.	Nu Way Organic Nature (Ind) Ltd.	Falls on 35' wide road 500 meters away from N.H-I	26.96
5.	Alliance Integrated Metallic Ltd.	Rajpura-Chandigarh road	69.00
6.	Siel Complex	Link road from bye-pass to village Sardargarh	635.00
7.	N.V. distillery and Regal distillery	Shambhoo - Ghanaur road	52.50
8.	Nabha Power Ltd. (Thermal Power Plant)	On proposed 50' wide link from Jansua-Saneta road	1278.16
Total			**2231.50acres (903.44 ha.)**

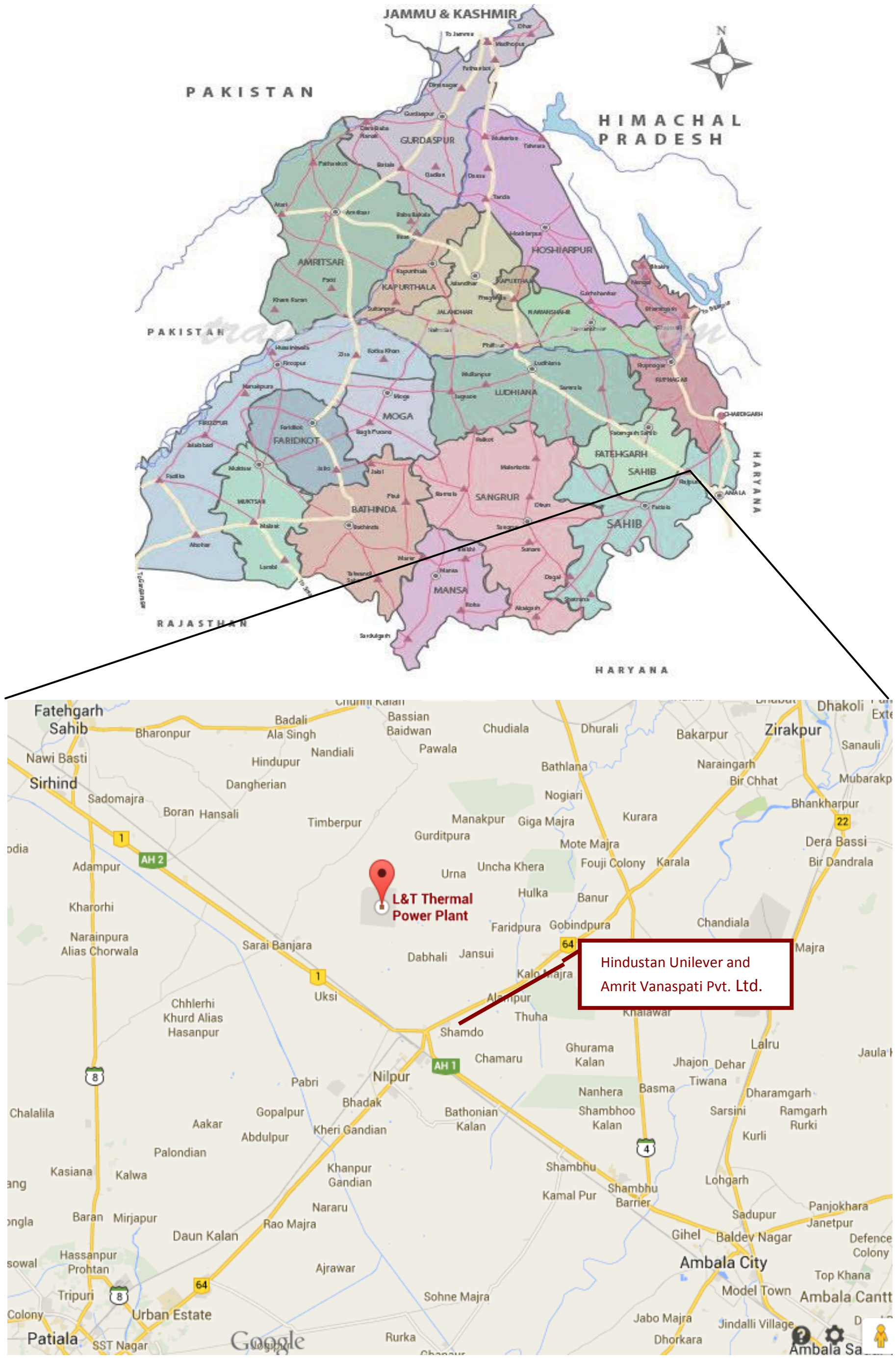

Figure 4.5 Location of the power plant and geographical characteristics of the study area

Figure 4.6 General view of the Rajpura Thermal Power Plant

4.3.2 Selection of sampling site and receptor points

The sampling sites include the major stacks of thermal power plant. On the basis of information collected from PPCB, two large scale industries namely Hindustan Unilever Pvt. Ltd. and Amrit Vanaspati Pvt. Ltd. located in Focal Point, Rajpura were selected as sampling sites for the present study.

With the help of Google map, the major receptor sites based on wind data, population density, topography and other local parameters of study area. Moreover residential areas and villages near to an industrial zone were given more preference as they get mostly affected from industrial pollution.

4.3.3 Meteorological Monitoring

The meteorological factors affect a range of atmospheric characteristics and dispersal of pollutants. The essential meteorological parameters required for modelling are wind speed, wind direction, ambient air temperature, relative humidity, rainfall, atmospheric pressure, cloud cover, ceiling height, mixing height and solar radiation. Meteorological data was collected for daily mean hourly data through-out the study period of one year i.e. January 1, 2013 to December 31, 2013 to ensure proper representation of the activities. Weather Monitoring Station was installed at DBTES, Thapar University (30°35'39''N, 76°37'07''E), Patiala. Additional meteorological data for the study period was collected form Indian Meteorological Department (IMD) Station ID-42101, Patiala. The meteorological data was valid to nearby 30 Km areas. Meteorological data then compiled in an excel file for further processing by AERMET and PC-RAMMET View program.

PC-RAMMET

The ISCST3 model calculates concentrations from user-specified meteorological data. It accepts hourly meteorological data preprocessed by PC-RAMMET or RAMMET, as well as ASCII formats. The input data requirements for PC-RAMMET or RAMMET depend on the dispersion model and the model options for which the data are being prepared. For estimating the concentration without taking into account the effect of settling and removal processes by dry and wet deposition, the necessary data are Wind direction (degree), Wind speed (m/s), Dry bulb temperature (˚C), Opaque cloud cover (okta), Morning mixing height (meter) and Afternoon mixing height (meter).

The mixing heights are based on upper air soundings at 1200 GMT and 0000 GMT, respectively.

The operations performed by PC-RAMMET include:

- Calculate hourly values for atmospheric stability from meteorological surface observations;
- Interpolate twice daily mixing heights to hourly values;
- Optionally, calculate the parameters for dry and wet deposition processes; and
- Output data in an unformatted or ASCII format required by regulatory air quality dispersion model ISCST3.

AERMET

AERMET is the meteorological pre-processor for AERMOD. AERMOD accepts hourly meteorological data, consisting of a "surface" file and a "profile" file that has been preprocessed by the AERMET that includes three stages of preprocessing of the meteorological data. The first two stages extract, quality check and merge the available meteorological data. The third stage requires input of certain surface characteristics (surface roughness, Bowen ratio, and albedo) that vary from site to site. The user needs to know whether the land use is water, deciduous forest, coniferous forest, swamp, cultivated land, grassland, urban, or desert shrub land *(Trinity, 1991).*

Wind roses are plotted. The necessary data collected for AERMET include Wind direction (degree), Wind speed (m/s), Dry bulb temperature (˚C), Relative humidity (%), Atmospheric pressure (mm-Hg), Rainfall (cm), Solar radiation (wat/m^2) and Opaque cloud cover (okta).

4.3.4 Source Emission Inventory

The dispersion of pollutants along with meteorological conditions also depends upon the source characteristic (such as emission rate, exit velocity of gases, exit temperature of gases, stack height and stack diameter) included in the emission inventory. The type of industry along with its production capacity, type of fuel used, peak working hours and other relevant data was collected from the Punjab Pollution Control Board (PBCB), Patiala. The emission inventory of the study area consists of three point sources.

1. Stacks of Thermal Power Plant
2. Stacks of Hindustan Unilever Pvt. Ltd.
3. Stacks of Amrit Vanaspati Pvt. Ltd.

As thermal power plant became operational in December, 2013, so stack monitoring measurement of Thermal Power plant was carried out in months of January to April, 2014 at the peak working hour of the plant.

Stack monitoring measurement campaign for Hindustan Unilever Pvt. Ltd. and Amrit Vanaspati Pvt. Ltd. was carried out at periodic intervals, such as once every three months at the peak working hour of the industry and the Sampling duration was kept at 20 minutes and frequency of stack sampling was done according to CPCB guidelines (Emission regulations, CPCB (1985) for the SO_2, NO_2 and SPM concentrations. These pollutants were measured at the stack of the industries continuously by Stack monitoring kit. The average emissions from representative stacks were taken to compile the emission inventory which is further used by ISCST3 and AERMOD.

4.3.5 Use of ISCST3 and AERMOD

In order to conduct a refined air dispersion modelling project using the U.S. EPA ISCST3 and AERMOD short term air quality dispersion model, the meteorological data of the area need to be processed using the U.S EPA PCRAMMET and AERMET program.

Models Run

A typical ISCST3 and AERMOD interface uses the six pathways to develop an input file. These pathways are Control pathway, Source pathway, Receptor pathway, Meteorological pathway, Terrain Grid pathway, and Output pathway.

CO- Control pathway: Control pathway is a collective term used to specify the overall job control options including titles, dispersion options, terrain options, and pollutant/ average time options. Dispersion option in the software gives the user a choice between the default and non-default options. Default options include the use of stack-tip downwash and a routine for processing averages when calm winds or missing meteorological data occur. Non-default options can be used for suppressing the use of stack-tip downwash and to disable the date checking for non-sequential meteorological data files.

SO- Source pathway: Source pathway feature enables the handling of multiple sources, including point, volume, and area source types. 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 point sources as source parameters.

RE- 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. Discrete and boundary receptors can also be defined. Concentrations can be calculated for all terrain elevations and for receptors above ground elevation (flagpole receptors). An unlimited number of receptor grids may be entered for each modeling run. An unlimited number of receptors can be modeled. The user has the ability to eliminate onsite and offsite receptors from the modeling analysis.

ME- Meteorology pathway: In the Meteorology pathway, the model uses a file of surface boundary layer parameters and a file of profile variables including wind speed, wind direction, and turbulence parameters. These meteorological inputs are generated by the meteorological preprocessor AERMET and RAMMET, as described earlier. It specifies the meteorological data file and information about the meteorological stations.

Terrain Grid pathway: In this pathway, the user may either use the terrain grid input file or may leave the option. In case the option is used, the user is required to specify the location of the terrain grid file in UTM coordinates.

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

4.3.6 Air Quality Monitoring and Analysis

Air quality monitoring for NO_2, SO_2 and SPM was carried out at periodic intervals at all the discrete receptors, such as once every three months during the study period for 24hr duration using HVS (high volume sampler) along with impinger train.

For the analysis of sulphur dioxide (SO_2), nitrogen dioxide (NO_2) and suspended particulate matter (SPM), Indian Standard methods IS 5182 (Part 2), IS 5182 (Part 6) and IS 5182 (Part 4):1999 were followed, respectively.

4.3.7 Validation of ISCST3 and AERMOD 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 concentrations due to the following: natural sources, nearby sources other than the one currently under review, and unidentified sources. Rajpura Thermal power plant being the dominating source of emission in the study area became operational in December, 2013. Thus, daily average background concentrations of NO_2, SO_2 and SPM pollutants was monitored at all the discrete receptors during the period October-November, 2013 using HVS (high volume sampler). These monitored background concentration were than superimposed with incremental concentration predicted by

ISCST3 and AERMOD model and validated against observed ground level concentration monitored at all the discrete receptors. Both ISCST3 and AERMOD were validated and compared for daily average concentration of SO_2, NO_2 and SPM using observed ground level concentration at all the receptor sites.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter incorporates the input data such as, source emission inventory, meteorological source and land use to generate wind roses and the isopleths for estimating concentrations of pollutants at different receptor points. Meteorological and source emission inventory was prepared to be used in Industrial Source Complex Short Term Version 3 (ISCST3) and American Meteorological Society/Environmental Protection Agency Regulatory MODel (AERMOD) software which were employed for modelling. ISCST3 and AERMOD models were used in order to estimate concentrations of air pollutants, namely SO_2, NO_2 and SPM for two different averaging periods i.e., annual average (long term) and daily average (short term). Following this, and in order also to validate and evaluate AERMOD and ISCST3, the daily mean concentration from both the models is compared using observed ground level concentration at all the receptor sites. As a result, different maximum Ground Level Concentration (GLC) values, different maximum GLC locations and different correlation graphs were obtained as result of modeling executions, thus showing the model performance.

5.1 Source emission inventory

The stacks (Point Source) of Rajura Thermal Power Plant located near Nalash village and about 8km from Rajpura town is the sampling site for the present study. The contribution of emissions from small combustion installations to the total emissions varies and depends on pollutants type and given region. Furthermore the influence of these emission sources on the local air quality could be significant due to the low height of the flue gas releases, even when their share in total emissions is not dominant. Thus, with the help of Google map different population clusters or zones with maximum population density and industrial clusters were identified. On this basis, two large scale industries namely Hindustan Unilever Pvt. Ltd. and Amrit Vanaspati Pvt. Ltd. located in Focal Point, Rajpura were also selected as sampling sites for this study. Therefore, additional emission inventory was prepared for the two representative industries. The source data of thermal power plant was collected from stack monitoring measurement campaign carried out at periodic intervals (once every three months for one year at the peak working hour) and the source data of two representative industries was collected from PPCB. The average emissions from representative stacks were taken to compile the emission inventory as shown in Tables 5.1, 5.2 and 5.3.

5.1.1 Stacks of Rajpura Thermal Power Plant

There are 5 stacks installed in the thermal power plant. There are two flues in main stack and both the flues are equipped with Electrostatic Precipitators (ESP). Table 5.1 shows the characteristics of stacks of thermal power plant as well as emission rates from the two main stacks.

Table 5.1 Stack characteristics of Thermal Power Plant

S. No	**Type & Capacity of Boiler/Stack**	**Height of stack**	**Dia of stack**	**Flue gas temp**	**Flue emission velocity**	**Name of emission**	**Emission rate (g/s)**		
							SPM	**SO_2**	**NO_2**
1.	2322TPH	275m	7.5m	410K	25m/s	SO_2, NO_x , SPM	79.45	1151	1035
2.	2322TPH	275m	7.5	421K	24.7m/s	SO_2, NO_x , SPM	79.34	1143	1027
3.	D.G set 3750KVa	30m	1m	Not in operation					
4.	Coal crusher house	48.25m	1.2m	Not in operation					
5.	Coal bunker house	95.19m	1.5m	Not in operation					

5.1.2 Stacks of Major Industrial Point Sources

There are 3 stacks installed in Hindustan Unilever Pvt. Ltd. and 3 stacks in Amrit Vanaspati Pvt. Ltd. Table 5.2 and 5.3 shows the characteristics and emission rates from the stacks of Hindustan Unilever Pvt. Ltd. and Amrit Vanaspati Pvt. Ltd., Rajpura, respectively.

Table 5.2 Stack characteristics of Hindustan Unilever Pvt. Ltd.

S. No	**Type & Capacity of Boiler/Stack**	**Height of stack**	**Dia of stack**	**Flue gas temp**	**Flue emission velocity**	**Name of emission**	**Emission rate (g/s)**		
							SPM	**SO_2**	**NO_2**
1.	8TPH	36m	0.635 m	365K	6.2m/s	SPM, NO_x	0.386	BDL	0.318
2.	D.G set 1010KVa	28.5m	0.46 m	493K	13.4m/s	SPM, NO_x	0.166	BDL	0.686
3.	D.G set 867KVa	13.7m	0.3m	378K	5.32m/s	SPM, NO_x	0.04	BDL	0.144

Notes: BDL=below determined level (Source: PPCB)

Table 5.3 Stack characteristics of Amrit Vanaspati Pvt. Ltd.

S. No	Type & Capacity of Boiler/Stack	Height of stack	Dia of stack	Flue gas temp	Flue emission velocity	Name of emission	Emission rate (g/s)		
							SPM	SO_2	NO_2
1.	6TPH	30m	1m	339K	6.89m/s	SPM, NO_x	0.458	BDL	0.308
2.	6TPH	30m	1.5m	398K	5.23m/s	SPM, NO_x	0.713	BDL	0.616
3.	10TPH	35m	1.2m	490K	8.31m/s	SPM, NO_x	0.559	BDL	0.332

Notes: BDL=below determined level (Source: PPCB)

5.2 Meteorological processing

Mean hourly meteorological data for one year period January 1, 2013 to December 31, 2013 was collected from Weather Monitoring Station (DBTES, Thapar University, Patiala) and Upper air data for the same year was collected from IMD, Pune for Station ID-42101, Patiala. This Surface and Upper air data was imported to RAMMET View and only surface data was imported to AERMET View as for upper air data, the AERMET has an option of upper air estimator that estimates upper air data from hourly surface data. The excel file was converted to Samson format (.sam) required to run RAMMET and AERMET.

5.2.1 RAMMET VIEW

In this study, PC-RAMMET was used to prepare meteorological input data for ISCST3. Surface data in SAMSON format and upper air data in SCRAM format was used as an input to RAMMET view (Figure 5.1) and output data in an ASCII format was generated which was further used by regulatory air quality dispersion model ISCST3. The mixing heights were based on upper air soundings at 1200 GMT and 0000 GMT, respectively.

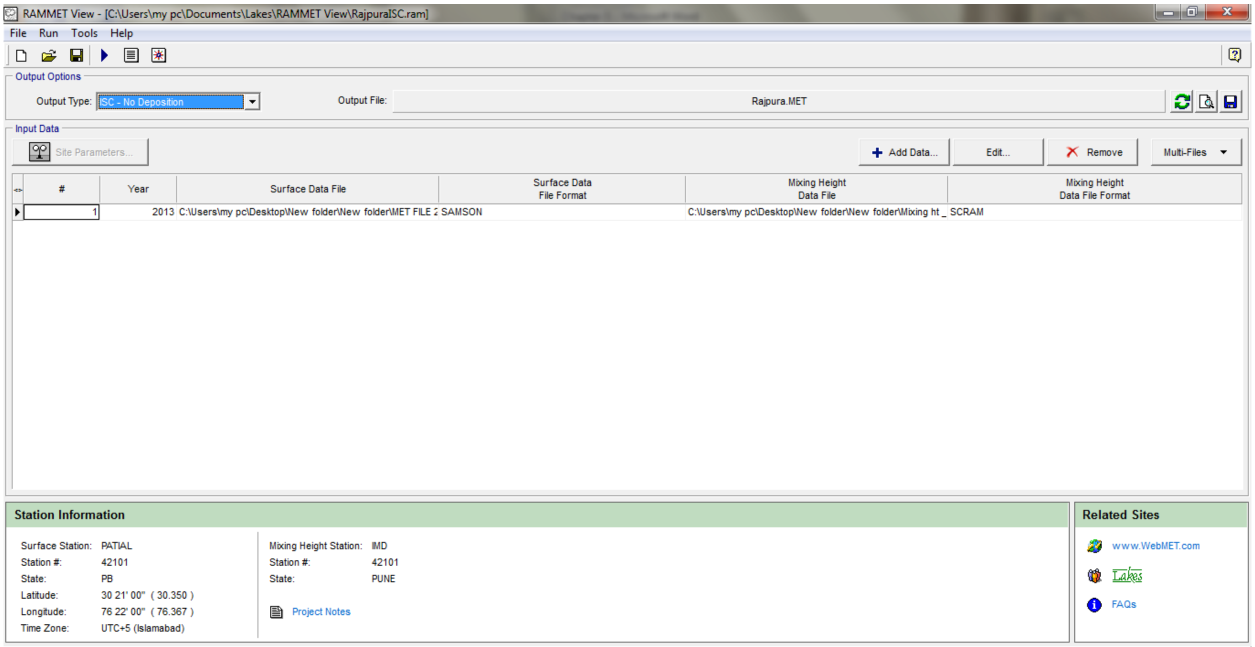

Figure 5.1 Screen shot for the main input window of RAMMET View 8.2.0

5.2.2 AERMET View

Surface data in SAMSON format was imported to AERMET View 8.0.5 (Figure 5.2). Along with surface data, upper air and surface characteristics were also imported. For upper air data, the software has an option of upper air estimator that estimates upper air data from hourly surface data. Surface parameters (Albedo, Bowen ratio and surface roughness) values were selected as per urban land use of the study area. Table 5.4 lists the albedo, Bowen ratio, and surface roughness that are assumed for this study.

Table 5.4 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

AERMET processes all input data in three stages and generated two output files (surface file and profile file) and wind rose plots. These files were further used as such for AERMOD.

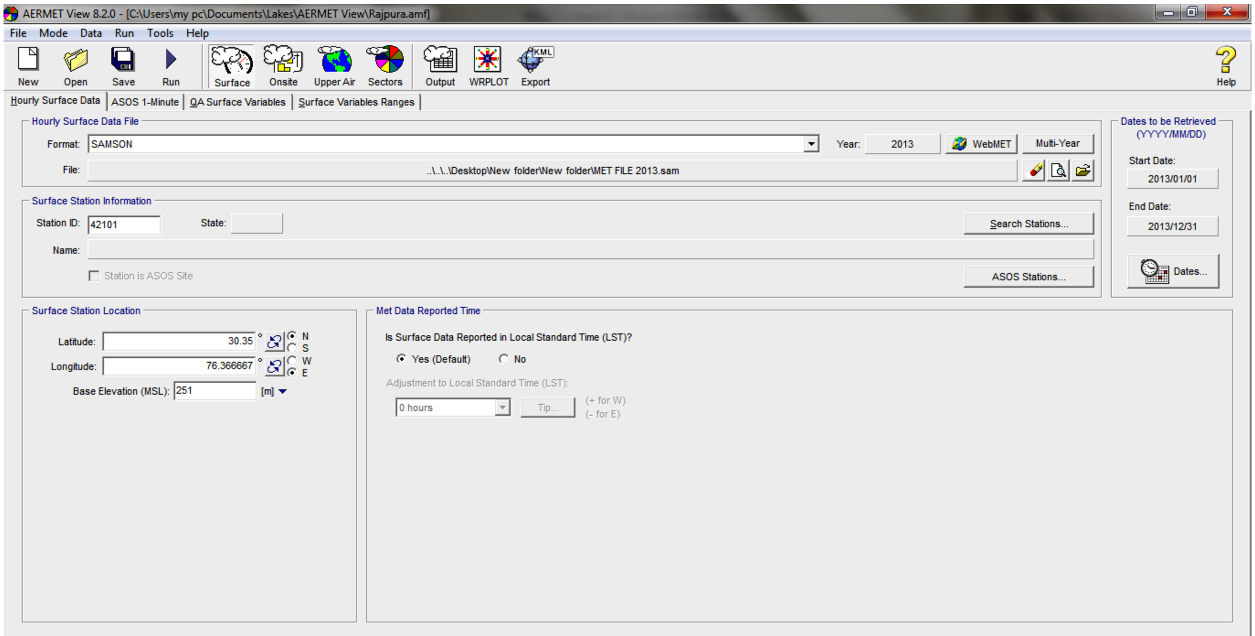

Figure 5.2: Screen shot for the main input window of AERMET View 8.2.0

5.3 Wind Roses

Based on hourly surface meteorological data and upper air data for period January 2013 to December 2013, wind rose was plotted based on the data processed in the pre-processors in order to present prevailing wind speeds and wind directions in the study area during 2013. Figure 5.3 shows the wind rose for the period between January 1, 2013 and December 31, 2013. According to figure, dominant wind direction were East, West and South-East with 73.38 % frequency of calm winds and the average wind speed was 1.51 m/s (1 Knot = 0.5144m/sec). Hence, this pictorial view showed the dispersion of pollutants was towards East, West and South-east side, the downwind distance up to which wind can cause pollutants to travel was further estimated with ISCST3 and AERMOD along with pollutants concentrations.

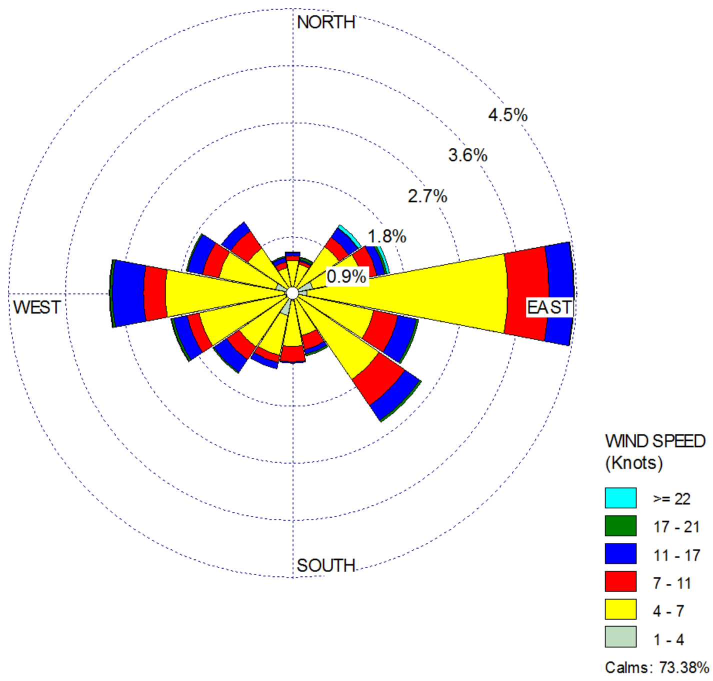

Figure 5.3 Annual wind rose in the study area for the year 2013

5.4 Receptor sites

Based on wind data, population density, topography and other local parameters of study area, receptors were selected. Moreover residential areas and villages near to an industrial zone were given more preference as they get mostly affected from industrial pollution.

With the help of Google earth, the study area were identified along with major receptor areas (Sural Kalan-A, Rai Majra-B, Sarai Banjara -C, Rajpura-D, Sirhind -E, Chattbir Zoo-F, Ambala-G, Patiala-H) shown in Figure 5.4. Blue, green and yellow pin point marks in the figure indicate the representative sampling stacks and red balloons marks indicates the sensitive receptors. Sural Kalan, Rai majra and Sarai Banjara being the nearby residential areas and villages to the thermal power plant were selected as receptor sites. Rajpura was selected on being the nearest town and industrial zone with high population density. Sirhind and Patiala were selected based on population density and other local parameters. Chattbir Zoo being the wildlife sensitive area and Ambala being the city with high population density were selected based on the wind direction, as they are on the east side of the study area where the wind profile has been dominant throughout the year (Figure 5.3). Table 5.5 shows the receptor points with distance and direction from the point source.

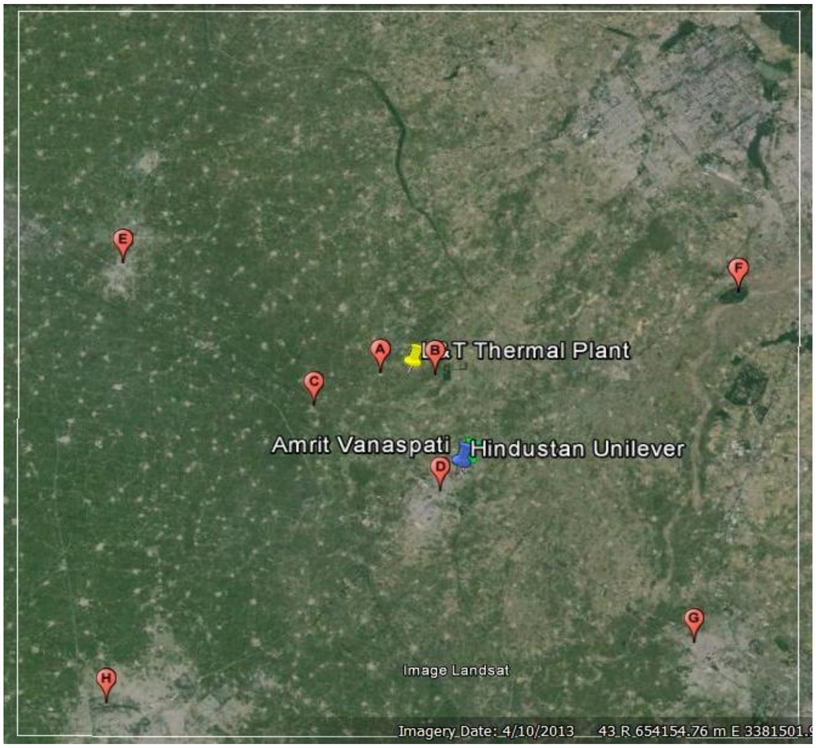

Figure 5.4 Study area with sampling sites and receptors

Table 5.5 Receptor points with distance and direction from the point source

Receptor Point	Name	Distance and Direction from the source
A	Sural Kalan	2 Km, W
B	Rai Majra	1.6 Km, E
C	Sarai Banjara	5.7Km,SW
D	Rajpura	7.7 Km, S
E	Sirhind	19.6Km,NW
F	Chattbir Zoo	22 Km, E
G	Ambala	25.6 Km, SE
H	Patiala	29.4 Km, SW

5.5 Models Run

After obtaining all the data needed to simulate the pollutants (NO_2, SO_2 and SPM) dispersion in the study area using ISCST3 and AERMOD, the modeling results were depicted as isopleths. Both the models have five mandatory pathways (Control, Source, Receptor, Meteorological and Output) and rest the use of two (Building and Terrain) pathways is optional and depends upon the conditions of study area. The study area is a flat terrain area and no building downwash was considered in this study. First of all, in **Control pathway** the type of pollutant (NO_2, SO_2 and SPM) and averaging time values for output concentrations of 24 h and annual was selected with rural dispersion coefficient.

In **Source pathway,** the data pertaining to the type of pollutant and the source characteristics (emission rate, exit velocity of gases, exit temperature of gases, stack height and stack diameter) data was incorporated.

In **Receptor pathway**, Uniform Cartesian grid and 8 discrete Cartesian receptors were located in base map to get the pollutant concentrations.

In **Meteorological pathway**, the output file of RAMMET, ASCII format (.met) was taken directly as meteorological input for ISCST3 and the output files of AERMET, surface and profile files (.sfc and .pfl) were taken directly as meteorological input for AERMOD.

In **Output Pathway**, the contour plot (isopleths) files were selected to get the output; they show the area of minimal to high concentrations. Averaging time was selected as 24 h and Annual averages for NO_2, SO_2 and SPM concentrations.

With the above specified conditions, ISCST3 and AERMOD were run twice for flat terrain for NO_2, SO_2 and SPM pollutants. In first run, both the ISCST3 and AERMOD models were run by only considering the stack characteristics of Rajpura Thermal Power Plant, and in the Second run, both the models were run by considering all the stack of other nearby major industrial point sources. Figure 5.5 and 5.6 shows the Screenshot of ISCST3 and AERMOD main windows having base map of study area.

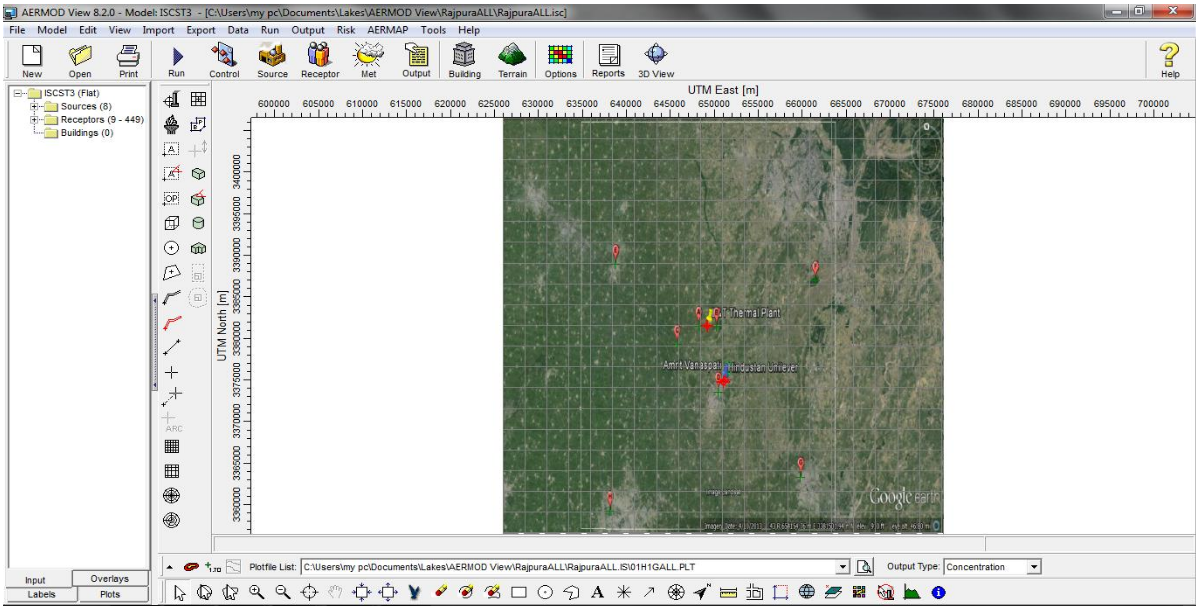

Figure 5.5 Screenshot of ISCST3 main windows having base map of study area

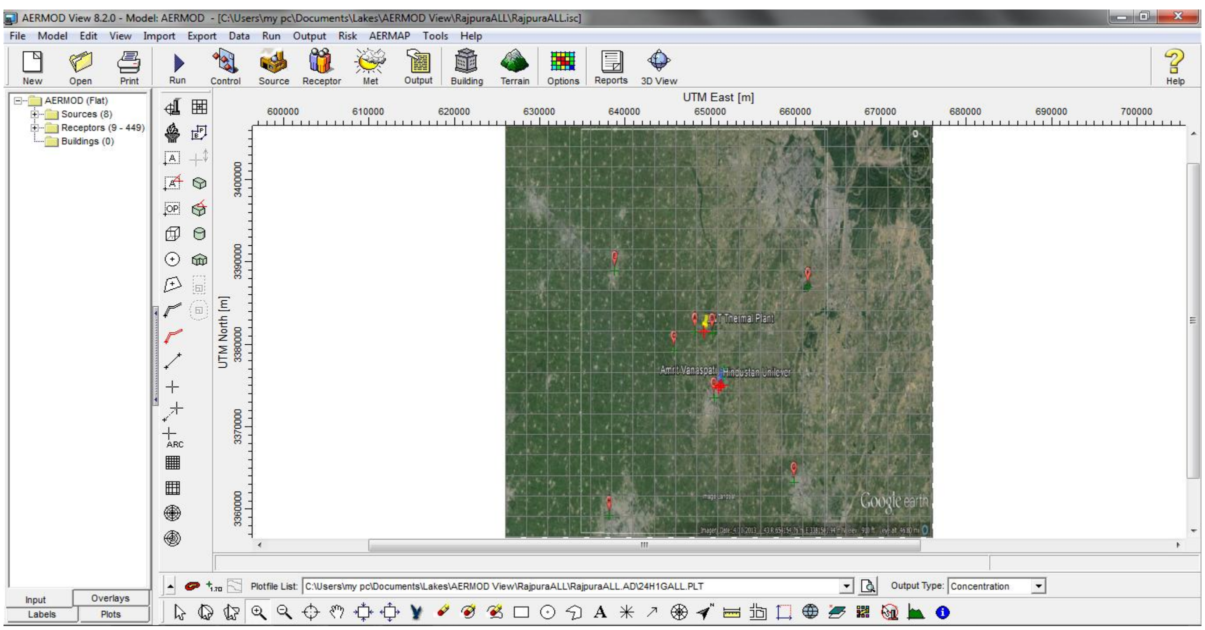

Figure 5.6 Screenshot of AERMOD main windows having base map of study area

5.6 Models prediction

With the help of UTM co-ordinates sampling sites and 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 NO_2, SO_2 and SPM were predicted and compared for Annual and daily (24 h) average time period.

5.6.1 Models prediction for NO_2

Air dispersion modeling results for incremental ground level concentrations of NO_2 on considering the source data of thermal power plant are presented in Figure 5.7 to 5.10 according to averaging periods.

Figure 5.7 and Figure 5.8 shows the effect of thermal power plant on annual average concentration of NO_2. ISCST3 and AERMOD estimated the maximum annual concentration due to power plant as 3 $\mu g/m^3$ and 11 $\mu g/m^3$ respectively. Thus, both the models have not shown good correlation between each other in estimating annual average SO_2 pollution at the study areas. The ground level concentration map plotted by AERMOD shows that power plant effects can be observed at further distances.

Figure 5.9 and Figure 5.10 shows the effect of thermal power plant on daily average concentration of NO_2. ISCST3 estimated the maximum daily concentration of NO_2 due to power plant as 38 $\mu g/m^3$ and AERMOD estimated 37 $\mu g/m^3$ as maximum daily average concentration of NO_2. The ground level NO_2 concentration maps of AERMOD are more characteristic than the ground level NO_2 concentration maps of ISCST3. According to ISCST3, the power plant contributes effectively to the NO_2 pollution at Rai Majra and Rajpura and according to AERMOD, the power plant contributes effectively to the NO_2 concentrations at Sural Kalan and Rai Majra, which are the nearby receptors to the thermal power plant.

Figure 5.7 ISCST3 annual average ground level concentrations (μg/m^3) of NO_2 due to power plant

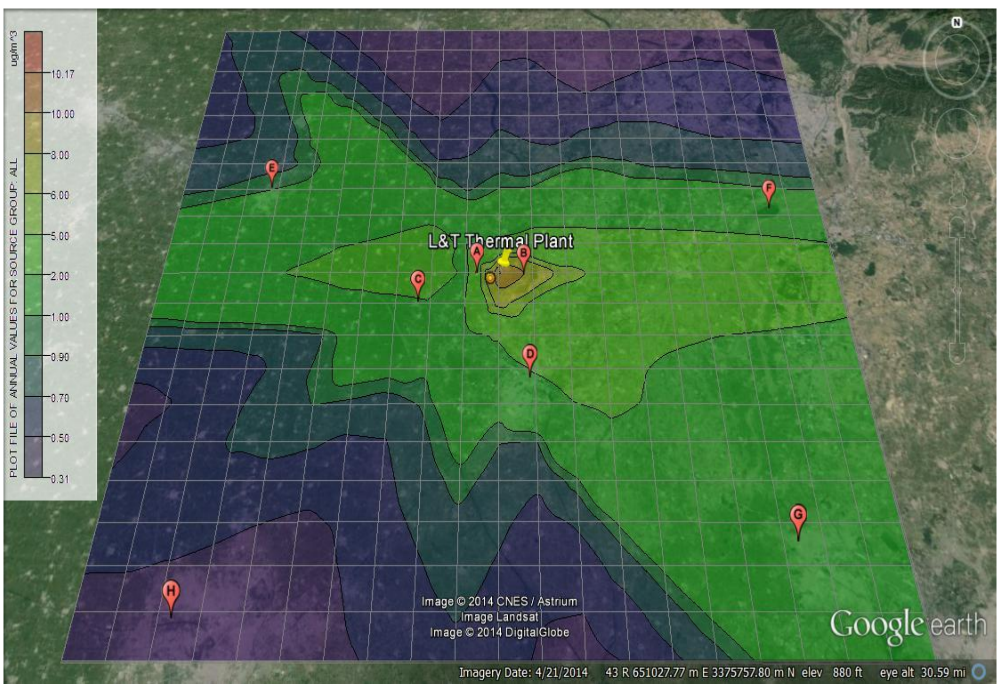

Figure 5.8 AERMOD annual average ground level concentrations (μg/m^3) of NO_2 due to power plant

Figure 5.9 ISCST3 daily average ground level concentrations (µg/m^3) of NO_2 due to power plant

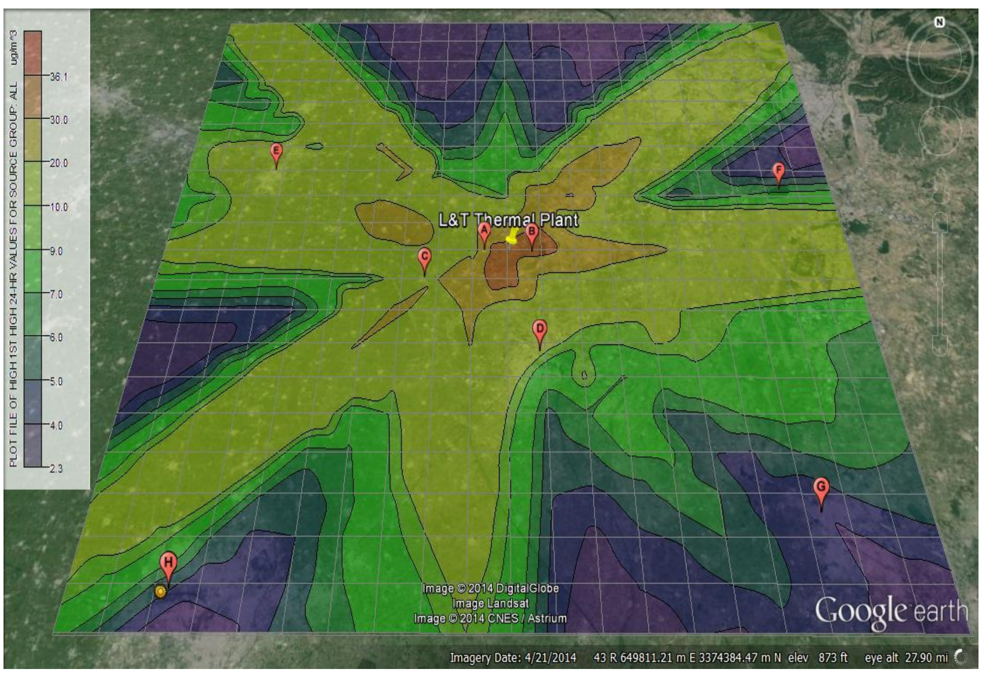

Figure 5.10 AERMOD daily average ground level concentrations (µg/m^3) of NO_2 due to power plant

5.6.2 Models prediction for SO_2

For the prediction of $SO_{2,}$ ISCST3 and AERMOD models were run considering source emission data of Thermal Power Plant since in the other sources the SO_2 emission was below the determined level as discussed earlier in source emission inventory. Air dispersion modeling results for incremental ground level concentrations of SO_2 is presented in Figure 5.11 to 5.14 according to averaging periods.

Figure 5.11 and Figure 5.12 shows the effect of thermal power plant on annual average concentration of SO_2. ISCST3 and AERMOD estimated the maximum annual concentration due to power plant at eastern part of the plant as 3 $\mu g/m^3$ and 12 $\mu g/m^3$ respectively. Thus, both the models have not shown good correlation between each other in estimating annual average SO_2 pollution at the study areas. The ground level concentration map plotted by AERMOD shows that power plant effects can be observed at further distances.

Figure 5.13 and Figure 5.14 shows the effect of thermal power plant on daily average concentration of SO_2. ISCST3 estimated the maximum daily concentration of SO_2 due to power plant as 43$\mu g/m^3$ and AERMOD estimated this quantity as 41$\mu g/m^3$. The ground level SO_2 concentration map of AERMOD is more characteristic than the ground level SO_2 concentration map of ISCST3. The effects of pollution sources are observed locally in AERMOD results. ISCST3 is able to present the effects of pollution sources at considerably far receptors.

Figure 5.11 ISCST3 annual average ground level concentrations (μg/m^3) of SO_2 due to power plant

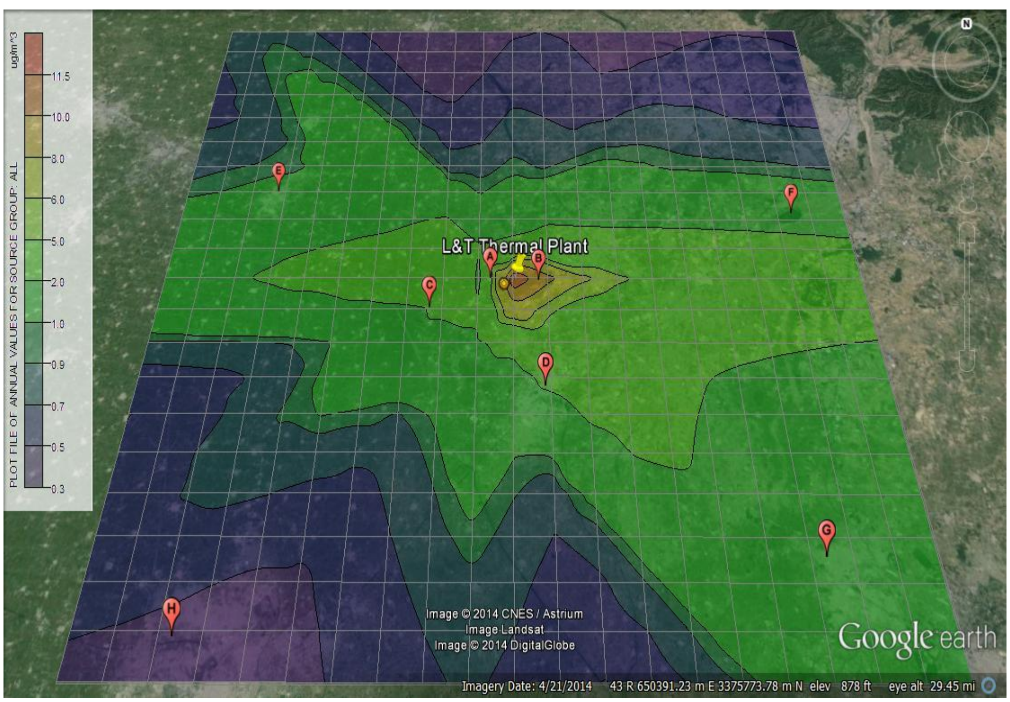

Figure 5.12 AERMOD annual average ground level concentrations (μg/m^3) of SO_2 due to power plant

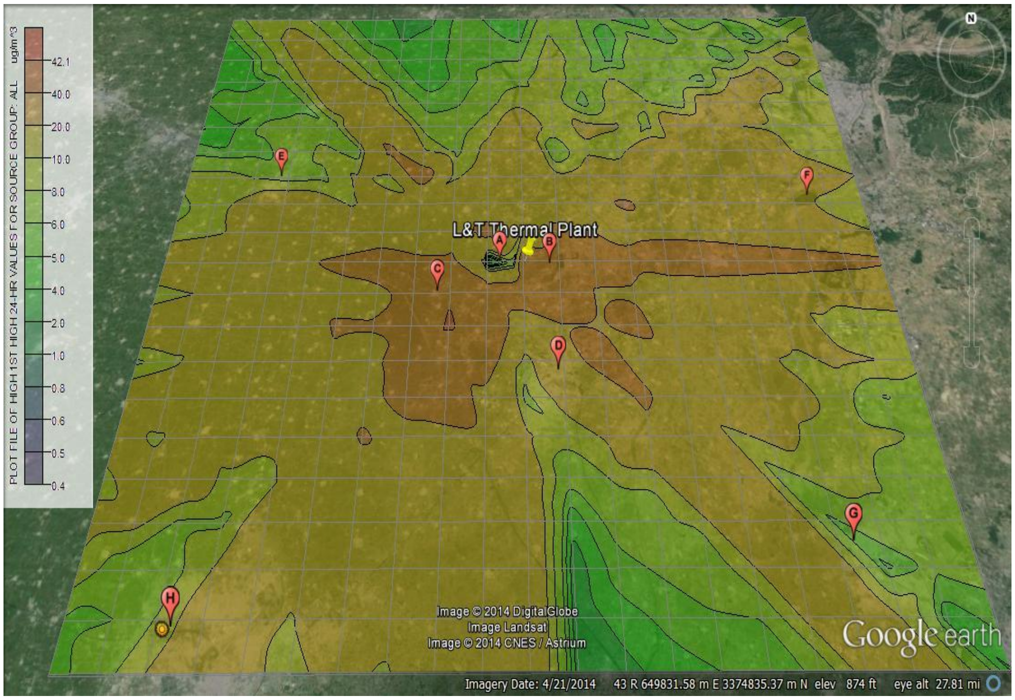

Figure 5.13 ISCST3 daily average ground level concentrations ($\mu g/m^3$) of SO_2 due to power plant

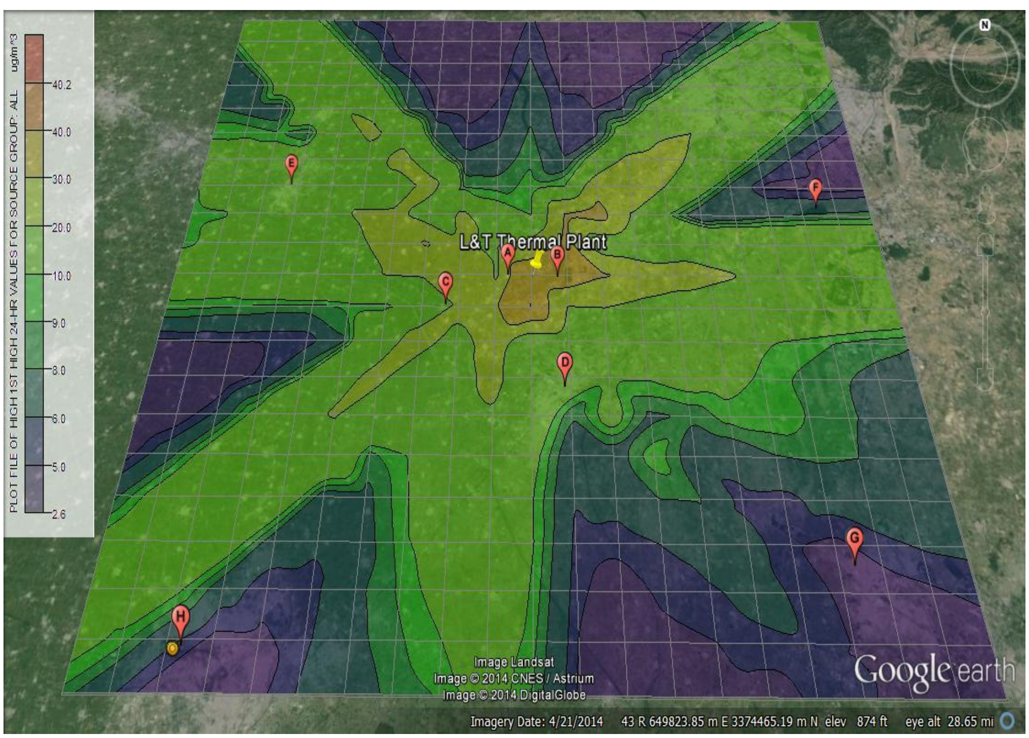

Figure 5.14 AERMOD daily average ground level concentrations ($\mu g/m^3$) of SO_2 due to power plant

5.6.3 Models prediction for SPM

Air dispersion modeling results for incremental ground level concentrations of SPM on considering the source data of thermal power plant are presented in Figure 5.15 to 5.18 according to averaging periods.

Figure 5.15 and Figure 5.16 shows the effect of thermal power plant on annual average concentration of SPM. ISCST3 and AERMOD estimated the maximum annual concentration due to power plant at east and south-east parts of the plant as 0.7$\mu g/m^3$ and 0.8$\mu g/m^3$ respectively. The concentration maps of maximum daily SPM concentrations are very similar for ISCST3 and AERMOD. The ground level concentration map plotted by ISCST3 and AERMOD shows that power plant effects can be observed at further distances in east and south-east direction.

Figure 5.17 and Figure 5.18 show the effect of thermal power plant on daily average concentration of SPM. ISCST3 estimated the maximum daily concentration of SPM due to power plant as 2.9$\mu g/m^3$ and AERMOD estimated this quantity as 3$\mu g/m^3$.

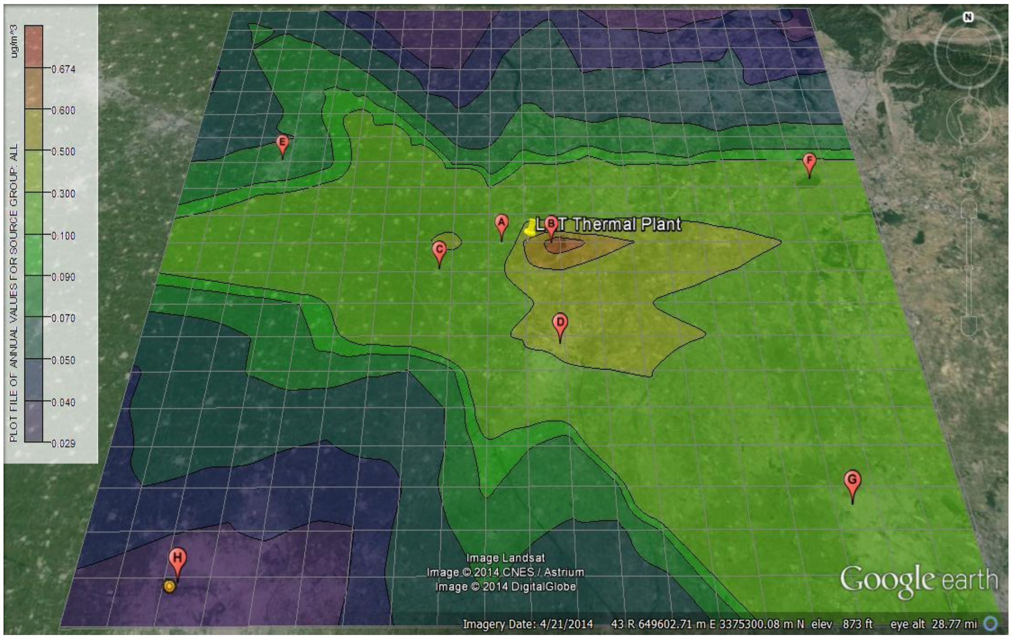

Figure 5.15 ISCST3 annual average ground level concentrations (µg/m^3) of SPM due to power plant

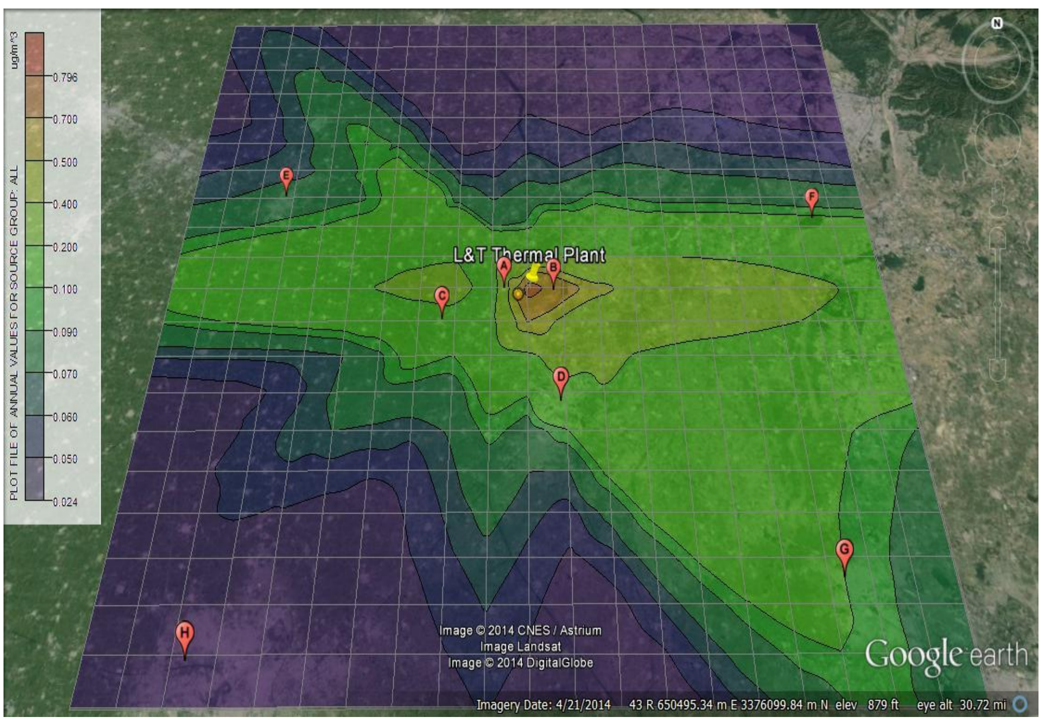

Figure 5.16 AERMOD annual average ground level concentrations (µg/m^3) of SPM due to power plant

Figure 5.17 ISCST3 daily average ground level concentrations (μg/m^3) of SPM due to power plant

Figure 5.18 AERMOD daily average ground level concentrations (μg/m^3) of SPM due to power plant

5.7 Comparison of ISCST3 and AERMOD

Although, the general pattern of the ground level pollution concentration maps estimated by both models are similar to each other, but the concentration predicted by models differ at various receptors.

5.7.1 Comparison of NO_2 predictions

For the prediction of NO_2, ISCST3 and AERMOD models were run by considering two source groups. In the first run, source emission data of thermal power plant was used and in the second run, all source emission data was used in source pathways of both the models. Table 5.6 summarizes the NO_2 results predicted by the models for only thermal power plant and Table 5.7 summarizes the NO_2 results predicted by the models for all sources.

Table 5.6 Predicted maximum incremental ground level concentration of NO_2 (ug/m^3) by AERMOD and ISCST for thermal power plant

Receptor	Receptors with distance from the source	Maximum incremental GLC of NO_2 (ug/m^3)			
		AERMOD		ISCST3	
		24hr	Annual	24hr	Annual
A	Sural Kalan (2km)	33.24836	5.98641	23.43286	1.81249
B	Rai Majra (1.6km)	37.73485	9.04454	31.19935	1.57809
C	Sarai Banjara (5.7km)	27.39123	4.49445	23.18962	2.43325
D	Rajpura (7.7km)	21.43521	3.54521	24.76401	2.00891
E	Sirhind (19.6km)	20.78483	1.27211	22.59278	1.86755
F	Chattbir Zoo (22km)	7.25847	1.48480	11.30366	1.88316
G	Ambala (25.6km)	5.45591	1.21944	7.93587	1.31247
H	Patiala (29.4km)	4.81548	0.44206	6.01869	0.59002

As can be seen from the Table 5.6, the annual and daily (24 h) average NO_2 concentrations predicted by AERMOD model are higher for the receptors near the source when compared to ISCST3 and, as the distance from the source increases both the models show not much difference in the predicted concentrations, ISCST3 predicting slightly higher concentration then AERMOD. The probable reason for difference in the models prediction results could be due to AERMOD's treatment of vertical air dispersion during unstable condition due to which surface releases encounters turbulence at the ground and is rapidly diluted so the maximum GLC occurs close to the source *(Silverman et al., 2007).*

Table 5.7 Predicted maximum incremental ground level concentration of NO_2 (ug/m3) by AERMOD and ISCST for all sources

Receptor	Receptors with distance from the source	Maximum incremental GLC of NO_2 (ug/m^3)			
		AERMOD		ISCST3	
		24hr	Annual	24hr	Annual
A	Sural Kalan (2km)	33.77876	5.76543	21.76401	1.98709
B	Rai Majra (1.6km)	38.75008	9.04454	29.09812	2.86450
C	Sarai Banjara (5.7km)	27.38051	3.77654	23.34561	2.08655
D	Rajpura (7.7km)	26.39316	4.65743	27.64015	2.67667
E	Sirhind (19.6km)	20.54778	1.34251	21.65467	1.68010
F	Chattbir Zoo (22km)	8.05740	1.52123	8.65420	1.99853
G	Ambala (25.6km)	5.32411	1.27864	7.00943	1.41020
H	Patiala (29.4km)	4.92341	0.48972	6.23144	0.61982

Table 5.7 summarizes the annual and daily (24 h) average NO_2 concentrations predicted by the models for all sources. As can be seen from the Table 5.7, the predicted annual GLC results of both the models are very similar to the GLC results predicted by both the models on considering the source data of thermal power plant as shown in Table 5.6. Thus, considering all the point sources, annual and daily average NO_2 concentrations predicted by AERMOD model are higher

for the receptors near the source when compared to ISCST3, as the distance from the source increases both the models show not much difference in the predicted concentrations, ISCST3 predicting slightly higher concentration then AERMOD. Thus it is clear from both the tables that maximum annual and daily NO_2 concentration was seen due to the Thermal Power Plant (almost 90% of the total concentration). For all the source data, both the models predict the highest annual and daily average concentration at same receptor i.e., Rai Majra, village near the thermal power plant. This was an expected result because the source emission rates of thermal plant are very high as compared to the other sources. The high combustion temperatures resulted in high NOx emissions from the boiler of the power plant. As the combustion temperature increases, the formation of thermal NOx also increases. On the other hand, low combustion temperatures do not result in significant NOx emission in small scale industries. Morover, there is no measure taken in order to reduce NOx emissions from the power plant. As a result, in the study area, high ground level NOx concentrations were found to be due to the Thermal Power Plant.

5.7.2 Comparison of SO_2 Prediction

For the prediction of $SO_{2,}$ ISCST3 and AERMOD models were run considering source emission data of Thermal Power Plant since in the other sources the SO_2 emission was below the determined level as discussed earlier in source emission inventory. Table 5.8 summarizes the SO_2 results predicted by the models for thermal power plant source.

Table 5.8 Predicted maximum incremental ground level concentration of SO_2 (ug/m3) by AERMOD and ISCST for thermal power plant

Receptor	Receptors with distance from source	Maximum incremental GLC of SO_2 (ug/m^3)			
		AERMOD		ISCST3	
		24hr	Annual	24hr	Annual
A	Sural Kalan (2km)	22.41383	4.98641	19.38148	1.91249
B	Rai Majra (1.6km)	39.64257	10.04454	32.89652	3.39809
C	Sarai Banjara (5.7km)	17.44843	4.49445	21.14872	1.43325
D	Rajpura (7.7km)	13.89999	5.02670	17.61222	2.60087
E	Sirhind (19.6km)	12.22326	2.27211	15.67204	1.98010
F	Chattbir Zoo (22km)	11.30016	2.78480	13.02548	1.78316
G	Ambala (25.6km)	10.06976	2.21944	7.15998	1.01247
H	Patiala (29.4km)	6.35726	0.94206	5.19964	0.79002

As can be seen from the Table 5.8, the annual average SO_2 concentrations predicted by AERMOD model are higher on all the receptor as compared to ISCST3 model. Both models point out that SO_2 emissions from the power plant are mostly effective on receptor sites, Rai Majra and Rajpura which are on prevailing wind direction in the study area. The difference in the models prediction results could be due to enhanced treatment of plume dispersion and growth in AERMOD *(Faulkner et al., 2008).*

Also, from the Table 5.8, for the daily (24 h) average period, maximum incremental ground level concentration of SO_2 shows variation in concentration predicted by both the models. AERMOD tends to predict higher concentration near the source than ISCST3 and as the distance of receptors increases from the source ISCST3 predicts higher concentration than AERMOD; except for receptor G and H i.e., Ambala and Patiala. According to the results of ISCST3, Rai Majra and Sarai Banjara are the mostly affected areas and according to the AERMOD, Sural Kalan and Rai Majra as these are near to the source. Although there are other residential areas closer to the power plant, SO_2 emissions do not contribute on these areas considerably according. The meteorological and the topographical properties of the study area are the major reasons for this. As depicted by both models, high stack height of the power plant (275 meters) make effects of the SO_2 emissions of the power plant very weak on these towns. Moreover, expected result of the daily average SO_2 concentration is high because Rajpura Thermal Power Plant is operating without Flue Gas Desulphurization system. This may be probable the reason for high emission rates from the stacks of thermal power plant. The difference in the results could be due to enhanced treatment of plume dispersion in AERMOD or incorporation of surface characteristics in AERMOD, which ISCST3 does not account in its dispersion modeling algorithms *(Faulkner et al., 2008).*

5.7.3 Comparison of SPM predictions

For the prediction of SPM, ISCST3 and AERMOD models were also run by considering two source groups. In the first run, source emission data of thermal power plant was used and in the second run, all source emission data was used, i.e., source emission inventory of thermal power plant, Hindustan Unilever Pvt. Ltd. and Amrit Vanaspati Pvt Ltd. Table 5.9 summarizes the SPM results predicted by the models for only thermal power plant. Table 5.10 summarizes the SPM results predicted by the models for all sources.

Table 5.9 Predicted maximum incremental ground level concentration of SPM (ug/m^3) by AERMOD and ISCST for thermal power plant

Receptor	Receptors with distance from the source	Maximum incremental GLC of SPM (ug/m^3)			
		AERMOD		ISCST3	
		24hr	Annual	24hr	Annual
A	Sural Kalan (2km)	2.29013	0.44613	0.99782	0.41765
B	Rai Majra (1.6km)	2.55320	0.68711	2.10209	0.55173
C	Sarai Banjara (5.7km)	2.41426	0.19534	2.21446	0.18093
D	Rajpura (7.7km)	1.03056	0.25453	1.53807	0.36481
E	Sirhind (19.6km)	0.82641	0.07876	0.77385	0.09425
F	Chattbir Zoo (22km)	0.87981	0.20735	1.27732	0.36615
G	Ambala (25.6km)	0.21907	0.10553	0.16476	0.18761
H	Patiala (29.4km)	0.56421	0.03436	0.69897	0.04623

As can be seen from the Table 5.9, the annual average SPM concentrations predicted by AERMOD model are higher for the receptors near the source when compared to ISCST3 for thermal power plant and, there is slight difference in the incremental concentration by both the models for the receptors which are far from the source. However, results of both the models show that the effect of Thermal Power Plants can be observed at nearby receptors i.e., Suarl Kalan and Rajpura. For daily average, AERMOD tends to predict higher concentration on the receptors A, B, E and G namely, Sural Kalan, Rai Majra, Sirhind and Ambala. ISCST3 predicts higher concentration than AERMOD for receptor C, D, F and H namely, Sarai Banjara, Rajpura, Chattbir Zoo and Patiala. The difference in the results could be due to enhanced treatment of plume dispersion in AERMOD or incorporation of surface characteristics in AERMOD, which ISCST3 does not account in its dispersion modeling algorithms *(Faulkner et al., 2008).*

Table 5.10 Predicted maximum incremental ground level concentration of SPM (ug/m3) by AERMOD and ISCST for all source

Receptor	Receptors with distance from source	Maximum incremental GLC of SPM (ug/m^3)			
		AERMOD		ISCST3	
		24hr	Annual	24hr	Annual
A	Sural Kalan (2km)	2.48216	0.54070	0.94930	0.51765
B	Rai Majra (1.6km)	2.91464	0.70981	2.34021	0.67119
C	Sarai Banjara (5.7km)	2.67538	0.37119	2.91979	0.33093
D	Rajpura (7.7km)	2.03134	0.39957	1.86533	0.56440
E	Sirhind (19.6km)	0.98452	0.08440	0.63870	0.09554
F	Chattbir Zoo (22km)	0.61297	0.20961	1.17848	0.31615
G	Ambala (25.6km)	0.39014	0.21089	0.31561	0.36761
H	Patiala (29.4km)	0.37082	0.03073	0.77140	0.04453

As can be seen from the Table 5.10, the predicted annual and daily (24 h) GLC results are very similar to the results predicted by both the models by considering the source emission of thermal power plant as shown in Table 5.9.

As can be seen from the Table 5.10, on considering all the point source both the models show variation in concentration predicted for daily (24 h) average period. Table 5.10 shows that AERMOD predict the highest concentration at receptors near the thermal power plant along with the receptors E and G i.e., Sirhind and Ambala whereas, ISCST3 predicts the highest concentration at receptors D, F and H namely, Rajpura, Chattbir Zoo and Patiala. The results of both tables show that considering source emission of either power plant or of all sources in both the models, maximum annual and daily SPM concentrations was observed due to the Thermal Power Plant (almost 89% of the total concentration) although, the particulate matter emission rate of Thermal Power Plant is very low. The reason is that electrostatic precipitators are working with high efficiency.

Thus, for the present study AERMOD predicted higher concentrations near the source for both annual and daily averaging time periods. The difference in these results could be due to enhanced treatment of plume dispersion in AERMOD or incorporation of surface conditions in AERMOD, which ISCST3 does not account surface characteristics in its dispersion modeling algorithms *(Faulkner et al., 2008).* As a plume moves downwind from the release point, it grows in both the vertical and horizontal directions. ISCST3 uses Gaussian models to calculate atmospheric dispersion in both the horizontal and vertical directions, whereas, AERMOD uses Gaussian models in both the horizontal and vertical directions only under stable conditions. Under unstable conditions, AERMOD uses a Gaussian model in the horizontal direction and a non-Gaussian probability density function in the vertical direction to account for the effects of vertical variations in wind and turbulence on air dispersion *(US EPA 2003).* Also, AERMOD takes into account wind and temperature changes above the stack top in stable meteorological conditions (i.e., little turbulence due to convection or buoyancy) and convective updrafts and downdrafts in unstable meteorological conditions (i.e., increased convective turbulence). However, ISCST3 does not account for convective turbulence *(Silverman et al., 2007).* Moreover, the underlying surface conditions at the receptors were handled differently by the two models. ISCST3 does not consider the underlying surface conditions at the receptors, whereas, AERMOD uses data on the underlying surface conditions at the receptors as well as data on seasonal variation in its meteorological preprocessor to calculate the values of albedo, bowen ratio, and surface roughness *(Silverman et al., 2007).* Thus, AERMOD embeds the more updated and realistic air dispersion processes that lead to more accurate.

Moreover, almost in all ground level pollution concentration maps, the results of ISCST3 show that pollutants are able to travel further locations but the concentration map of AERMOD being more characteristics in depicting the concentration than ISCST3. The probable reason could be ISCST3 using Briggs equations with stack-top wind speed and vertical temperature gradient in all stability conditions. However, AERMOD uses Briggs equations with winds and temperature gradient at stack top and half- way to final plume rise at stable conditions; in convective conditions, plume rise is superposed on the displacements by random convective velocities *(U.S. EPA, 2003).*

In the study area, most polluted locations were on the prevailing wind direction of the study area. The wind allows for transport of air pollution over long distances. Through this pollution transport, even clean areas with no significant air pollution can be affected by air pollution transported from other regions which produce pollution. Thus, wind direction and wind speed are the other major reasons for the distribution of the pollutants. According to most of the results of the both models, high pollution concentrations are observed on South-East and East directions of the emission sources which are the dominant wind directions in the study area.

5.8 Validation of Model Performance

Performance validation shows the accuracy of the predictions of the models. The best way for the validation of the model performance is to compare the predicted results from the model with the actual observed values. Moreover, background sources are considered as an essential element of the total air quality analysis when examining source impacts. Background air quality consists of prevailing pollutant concentrations due to natural sources, nearby sources and unidentified sources. As, Rajpura Thermal power plant being the dominating source of emission in the study area became operational in December 2013, so, background concentrations of NO_2, SO_2 and SPM were monitored at all the discrete receptors during the period October to November, 2013. The monitored values were then superimposed with predicted maximum daily (24 h) average incremental concentration predicted by ISCST3 and AERMOD model and validated against observed ground level concentration at all the discrete receptors. Ambient air monitoring for daily averaging period was carried out at periodic intervals such as once every three months at all the discrete receptors during the period January to May, 2014 using HVS (high volume sampler). Performance validation of the models was done for NO_2, SO_2 and SPM pollutants and location separately. Coefficient of correlation graphs for both the models were plotted depicting better model performance and makes results feasible for further uses.

5.8.1 Model Performance Validation for SO_2 Predictions

Ambient air measurements of SO_2 concentration on each receptor before and after the operation of thermal power plant are given in Table 5.11. Evaluation of AERMOD and ISCST3 for Ground Level Concentration of the SO_2 is furnished in Table 5.12. Also, Figure 5.19 shows the comparison between the observed and predicted ground level SO_2 concentrations by AERMOD and ISCST3.

Table 5.11 Ambient air measurements and background measurement for SO_2 concentration

Receptor	Name of receptor	Background concentration in ug/m^3 (before the TPP operation)	Observed GLC in ug/m^3 (after the TPP operation)
A	Sural Kalan	12.8	48.51
B	Rai Majra	11.2	51.23
C	Sarai Banjara	13.8	37.34
D	Rajpura	27.2	37.09
E	Sirhind	23.45	27.40
F	Chattbir Zoo	15.23	23.90
G	Ambala	24.92	29.42
H	Patiala	5.99	8.71

Table 5.12 Evaluation of AERMOD and ISCST3 for Ground Level Concentration of the SO_2

Receptor	Name of receptor	Predicted GLC of SO_2 (ug/m^3)		Observed GLC (ug/m^3)
		AERMOD	ISCST3	
A	Sural Kalan	35.21	32.18	48.51
B	Rai Majra	50.84	49.09	51.23
C	Sarai Banjara	31.24	34.94	37.34
D	Rajpura	41.09	44.81	37.09
E	Sirhind	35.67	39.12	27.40
F	Chattbir Zoo	26.53	28.25	23.90
G	Ambala	34.98	32.07	29.42
H	Patiala	12.34	11.18	8.87

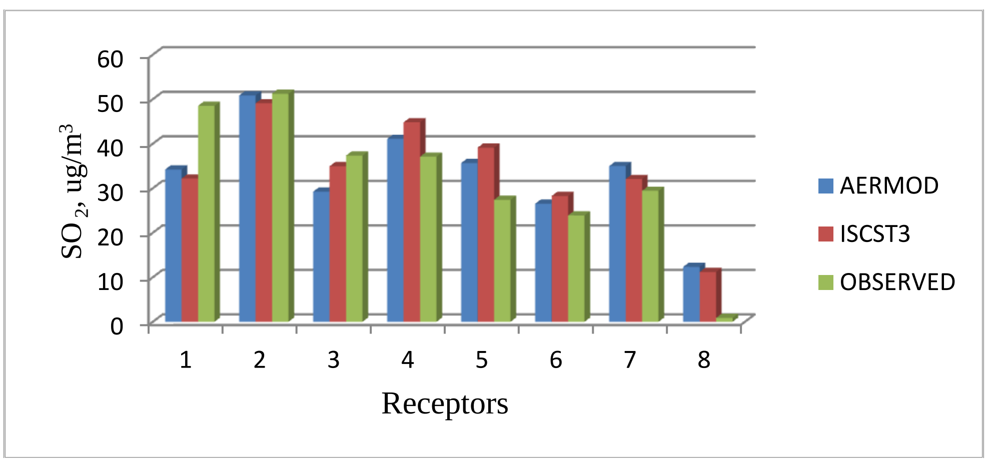

Figure 5.19 Comparisons of observed concentrations of SO_2 with predicted concentration by ISCST3 and AERMOD

As depicted in Figure 5.19, at four receptors namely; Sarai Banjara, Rajpura, Sirhind and Chattbir Zoo, ISCST3 estimates higher SO_2 concentrations when compared to AERMOD and at four receptors namely; Sural Kalan, Rai Majra, Ambala and Patiala, AERMOD estimates higher SO_2 concentrations when compared to ISCST3. The highest SO_2 concentration was observed at receptor Rai Majra which is the closest receptor to the Thermal Power Plant in direction of the dominant wind in the study area.

Moreover, both ISCST3 and AERMOD were under predicting the observed values at first three receptors which may be attributed to the fact that models can not demonstrate long range transport of the SO_2 at the receptor points located out of these three receptors. Other possible reason might be the building downwash effect. In real situation, building downwash effect results in high pollution concentrations close to residential areas. Pollutant plume hits the buildings and cause high concentrations at these locations. This effect was not included in model runs and that may have caused under predictions for both models *(US EPA 2003).* Similar results were predicted by *Dolek, 2007* in comparison of ISCST3 and AERMOD air dispersion models for SO_2 at area around Cayirhan Thermal Power Plant, Turkey.

Figure 5.19 also shows that both ISCST3 and AERMOD over predict the observed values at all other receptors namely; Rajpura, Sirhind, Chatbbir Zoo, Ambala and Patiala. The possible reason could be the difference in background concentration which was monitored and superimposed with the incremental concentration of ISCST3 and AERMOD on these receptors before the plant became operational is comparable to the ambient air concentration which was monitored on the same receptors after the power plant became operational.

Comparisons of the observed concentration with the predicted concentration of SO_2 at all the receptors are shown in correlation graphs given in Figure 5.20 and Figure 5.21.

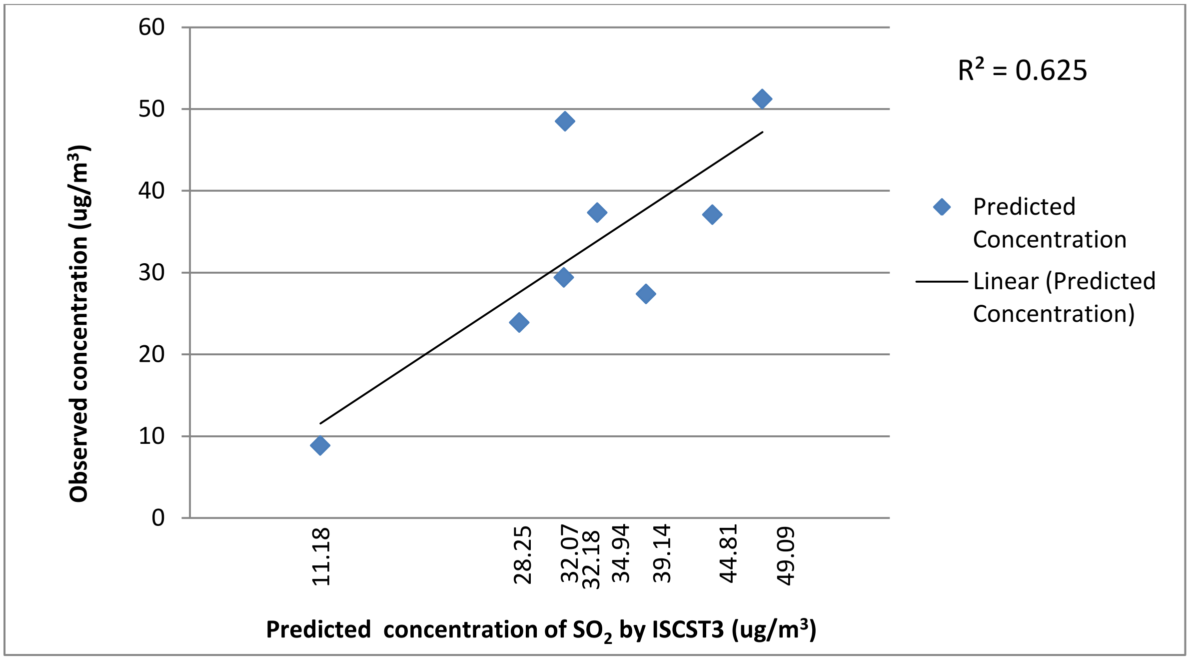

Figure 5.20 SO_2 predicted (ISCST3) concentration Vs Observed concentration

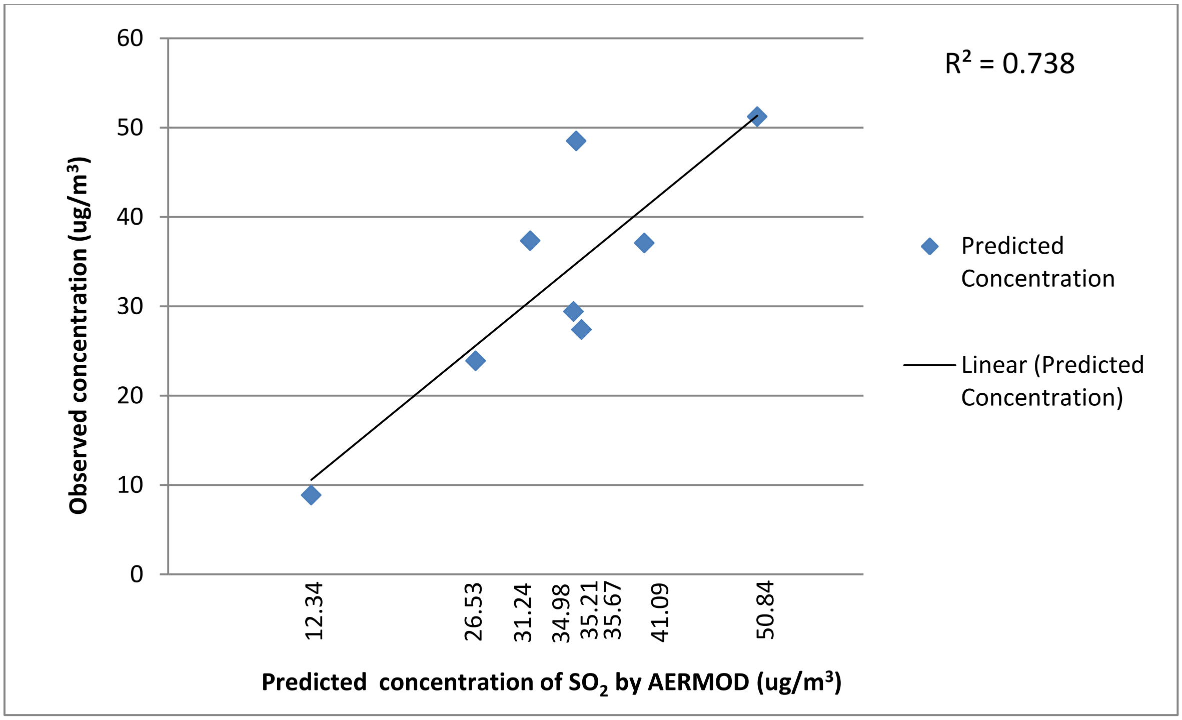

Figure 5.21 SO_2 predicted (AERMOD) concentration Vs Observed concentration

In Figure 5.20 and Figure 5.21, the coefficient of correlation is 0.625 and 0.738 respectively, so, the AERMOD model may be considered to be more validate in nature. Hence, AERMOD model has been considered better model in predicting the GLC of pollutants at various receptors points.

5.8.2 Model Performance Validation for NO_2 Predictions

Ambient air measurements of NO_2 concentration on each receptor before and after the operation of thermal power plant are given in Table 5.13. Evaluation of AERMOD and ISCST3 for GLC of the NO_2 is furnished in Table 5.14. Also, Figure 5.22 shows the comparison between the observed and predicted ground level NO_2 concentrations by ISCST3 and AERMOD.

Table 5.13 Ambient air measurements and background measurement for NO_2 concentration

Receptor	Name of receptor	Background concentration in ug/m^3 (before the TPP operation)	Observed GLC (ug/m^3) (after the TPP operation)
A	Sural Kalan	16.8	53.57
B	Rai Majra	13.2	57.81
C	Sarai Banjara	19.9	43.43
D	Rajpura	31.7	59.67
E	Sirhind	24.29	37.12
F	Chattbir Zoo	17.45	23.13
G	Ambala	21.26	32.10
H	Patiala	9.77	11.61

Table 5.14 Evaluation of AERMOD and ISCST3 for Ground Level Concentration of the NO_2

Receptor	Name of receptor	Predicted GLC of NO_2 (ug/m^3)		Observed GLC (ug/m^3)
		AERMOD	ISCST3	
A	Sural Kalan	50.04	40.23	53.57
B	Rai Majra	50.93	44.39	57.81
C	Sarai Banjara	47.29	43.08	43.43
D	Rajpura	53.13	56.46	59.67
E	Sirhind	45.57	46.88	37.12
F	Chattbir Zoo	24.7	28.75	23.13
G	Ambala	26.71	29.19	32.10
H	Patiala	14.58	15.78	11.61

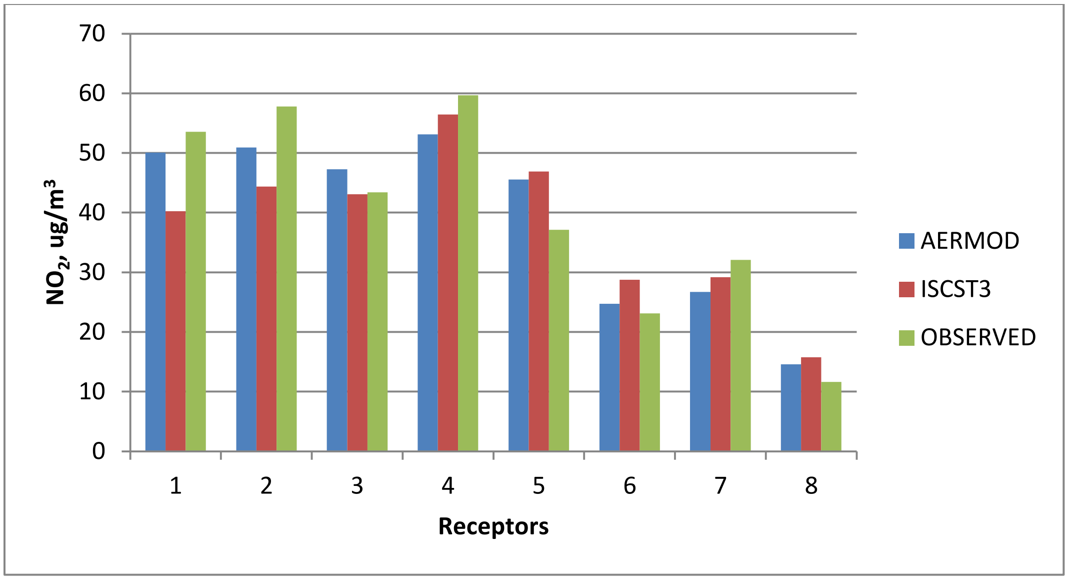

Figure 5.22 Comparisons of observed concentrations of NO_2 with predictions of ISCST3 and AERMOD

As depicted in Figure 5.22, five receptors namely; Rajpura, Sirhind, Chatbbir Zoo, Ambala and Patiala, ISCST3 estimates higher NO_2 concentrations than AERMOD and at three receptors namely; Sural Kalan, Rai Majra and Sarai Banjara, AERMOD estimates higher NO_2 concentrations than ISCST3. Thus, results clearly depicts that AERMOD predicted higher concentration at the nearby receptors to the source when compared to ISCST3, which predicted higher concentration at the receptors far away from the source. Both models estimate NO_2 concentrations close to each other at most of the receptor points. Models show that emissions from power plant may descend over these sites in high amounts. However, life time of NO_x in the atmosphere is short which is 1-2days, because NO_x is affected from wet and dry depositions *(Baumbach, 1996)*. In the assumptions of the both models, these depositions were not considered in order to point out the worst case at the study area.

The predictions of both ISCST3 and AERMOD were under predicting the observed values at receptors namely; Sural Kalan, Rai Majra, Rajpura and Ambala. Figure 5.22 also shows that both ISCST3 and AERMOD over predict the observed values at all other receptors namely; Sarai Banjara, Sirhind, Chattbir Zoo and Patiala. The probable reason could be the difference in background concentration which was monitored and superimposed with the incremental concentration of ISCST3 and AERMOD on these receptors before the plant became operational is comparable to the ambient air concentration which was monitored on the same receptors after the power plant became operational.

Comparisons of the observed concentration with the predicted concentration at all the receptors are shown in correlation graphs given in Figure 5.23 and Figure 5.24.

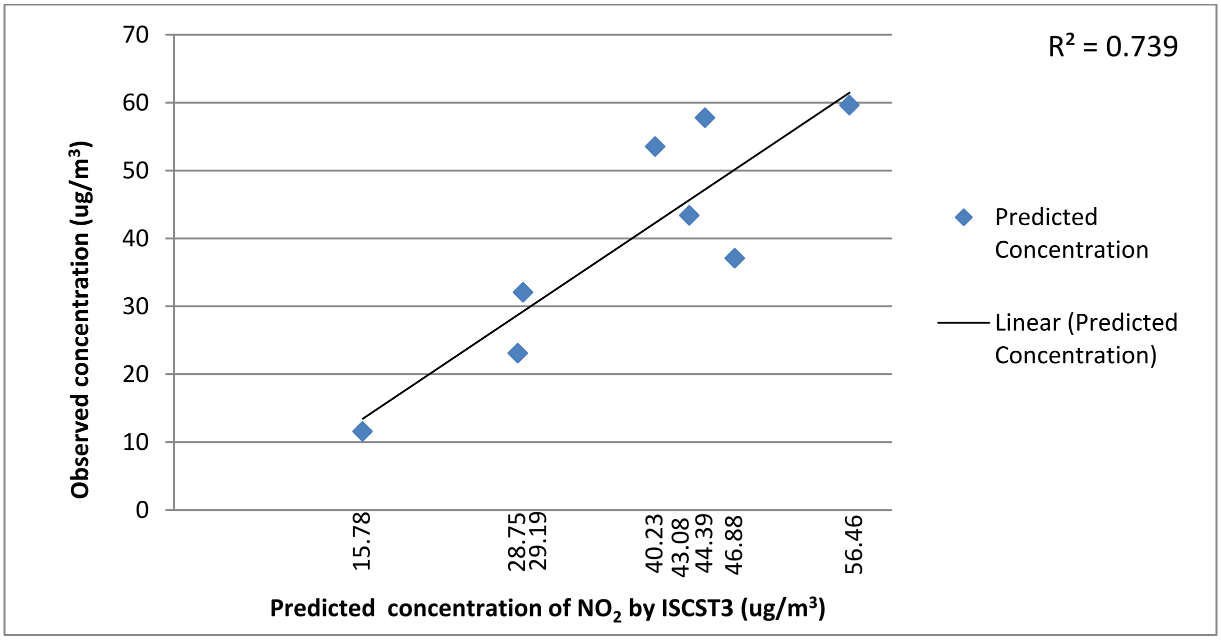

Figure 5.23 NO_2 predicted (ISCST3) concentration Vs Observed concentration

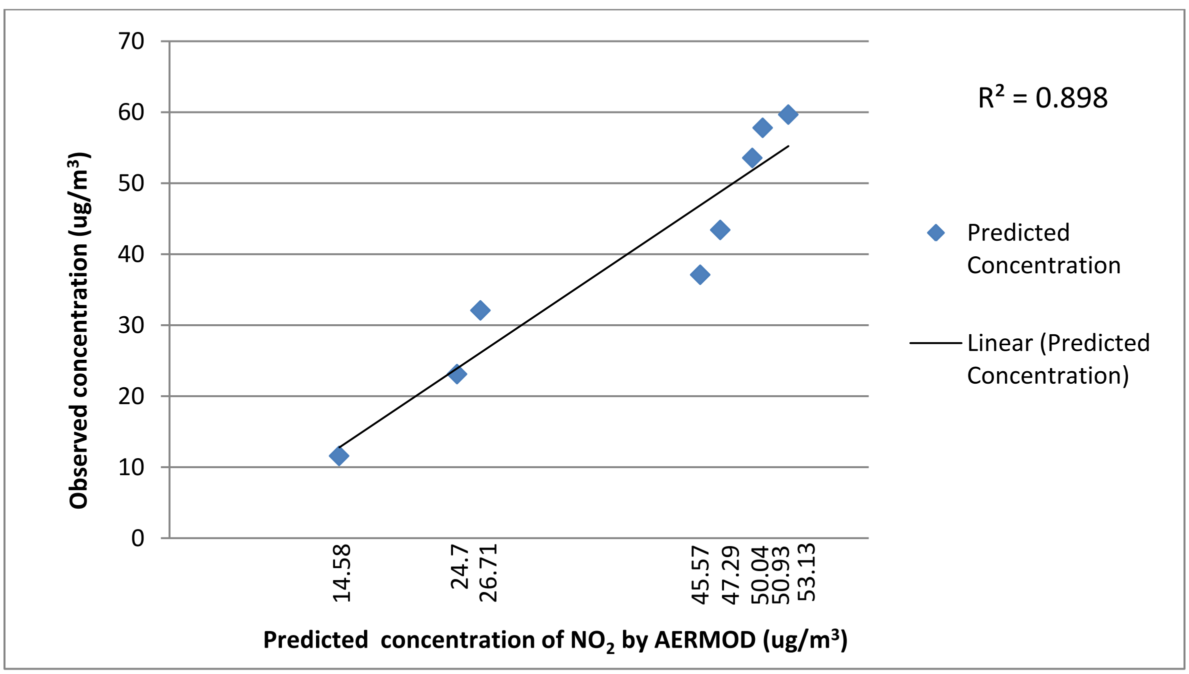

Figure 5.24 NO_2 predicted (AERMOD) concentration Vs Observed concentration

In Figure 5.23 and Figure 5.24 the coefficient of correlation is 0.739 and 0.898 respectively. The value of R^2 in Figure 5.24 is higher than the Figure 5.23 which indicates that AERMOD predictions are close to observed values when compared to ISCST3. So, similar to SO_2 results, AERMOD model may be considered to be more validate in nature. Hence, AERMOD model has been considered better model in predicting the GLC of pollutants at various receptors points.

5.8.3 Model Performance Validation for SPM Predictions

Ambient air measurements of SPM concentration on each receptor before and after the operation of thermal power plant are given in Table 5.15. Evaluation of AERMOD and ISCST3 for GLC of the SPM is furnished in Table 5.16. Figure 5.25 shows the comparison between the observed and predicted ground level SPM concentrations by ISCST3 and AERMOD.

Table 5.15 Ambient air measurements and background measurement for SPM concentration

Receptor	Name of receptor	Background concentration in ug/m^3 (before the TPP operation)	Observed GLC (ug/m^3) (after the TPP operation)
A	Sural Kalan	109.9	127.3
B	Rai Majra	93.1	143.4
C	Sarai Banjara	118.3	157.5
D	Rajpura	218.8	239.3
E	Sirhind	170.4	177.4
F	Chattbir Zoo	97.21	102.4
G	Ambala	177.78	187.4
H	Patiala	89.39	94.5

Table 5.16 Evaluation of AERMOD and ISCST3 for Ground Level Concentration of the SPM

Receptor	Name of receptor	Predicted GLC of SPM (ug/m^3)		Observed GLC (ug/m^3)
		AERMOD	ISCST3	
A	Sural Kalan	112.19	110.89	127.3
B	Rai Majra	95.65	95.2	143.4
C	Sarai Banjara	120.71	120.51	157.5
D	Rajpura	219.83	220.63	239.3
E	Sirhind	171.22	171.17	177.4
F	Chattbir Zoo	98.08	98.48	102.4
G	Ambala	177.99	177.94	187.4
H	Patiala	89.95	90.08	94.5

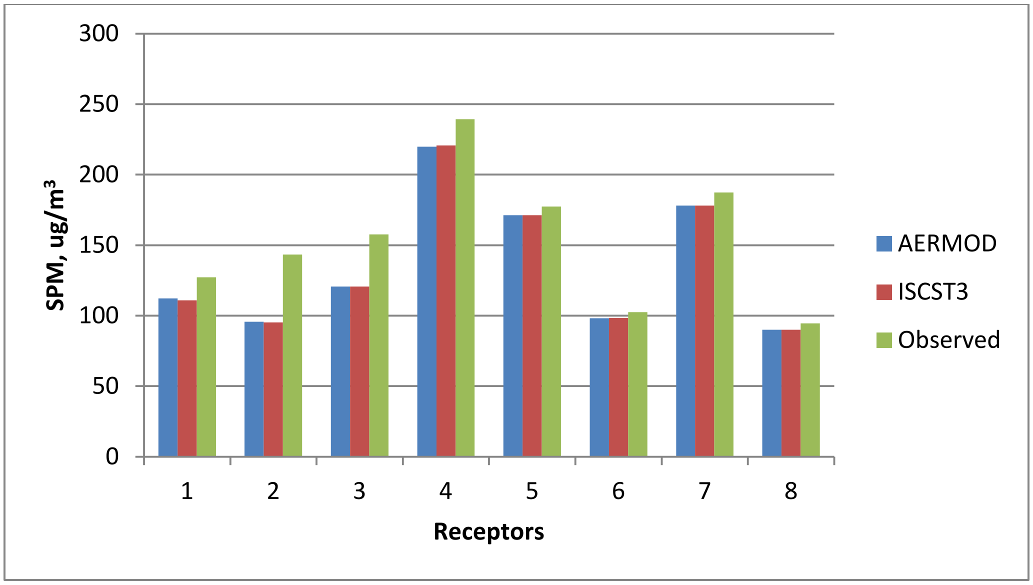

Figure 5.25 Comparisons of observed concentrations of SPM with predictions of ISCST3 and AERMOD

As depicted in Figure 5.25, both AERMOD and ISCST3 predicted GLC of SPM is similar to each other on all the receptor points. Receptor site Rajpura presents the highest SPM concentration among all the receptors. The probable reason could be the high background concentration observed at Rajpura. Also, the vehicular emissions which are the major source of SPM concentration in ambient air need to be considered.

Moreover, Figure 5.25 depicts that predictions of both ISCST3 and AERMOD were under predicting the observed concentration at all receptors. The possible reason could be that models can not demonstrate long range transport of the SPM at all the receptors. Other probable reason could be the low particulate matter emission rate of Thermal Power Plant because the electrostatic precipitators are working with high efficiency. Also, the vehicular emissions which are the major source of SPM concentration in ambient air have been considered. Therefore, models were not able to estimate SPM concentration as high as observed concentration at all the receptors because ambient air measurements before and after the operation of thermal power plant shows comparatively higher results.

Comparisons of the observed concentration with the predicted concentration at all receptors are shown in correlation graphs given in Figure 5.26 and Figure 5.27.

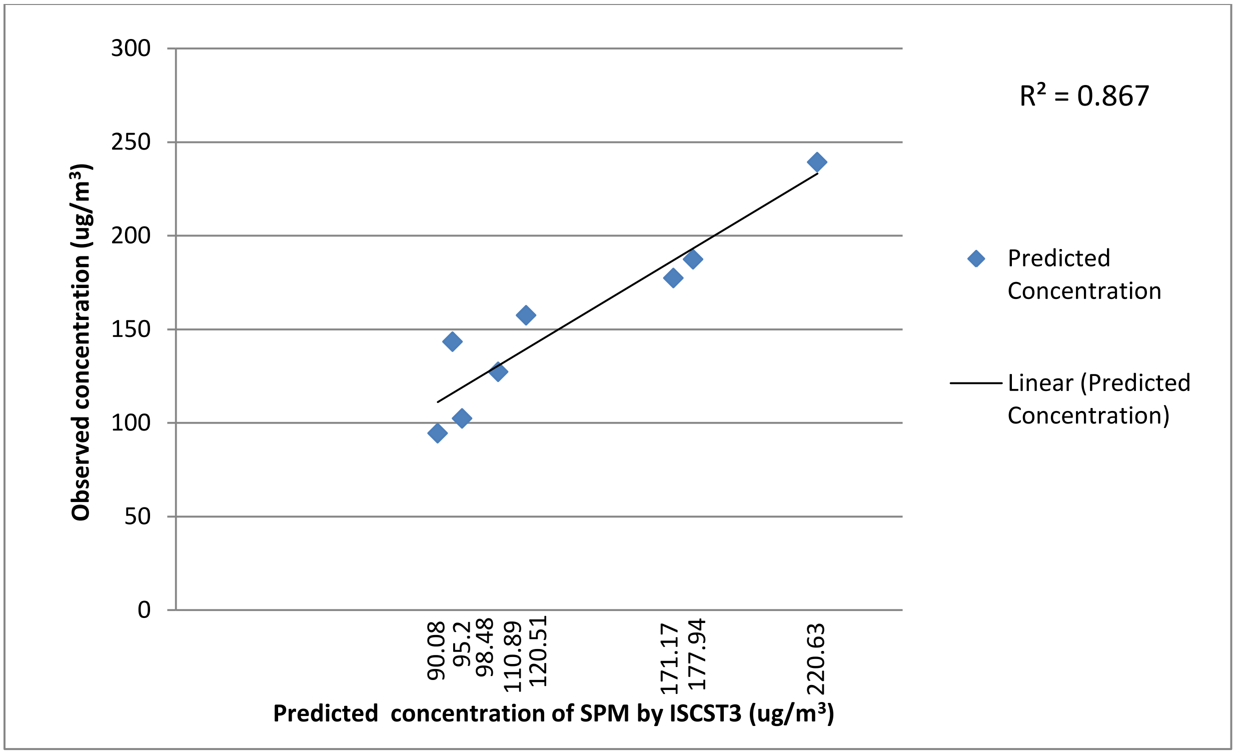

Figure 5.26 SPM predicted (ISCST3) concentration Vs Observed concentration

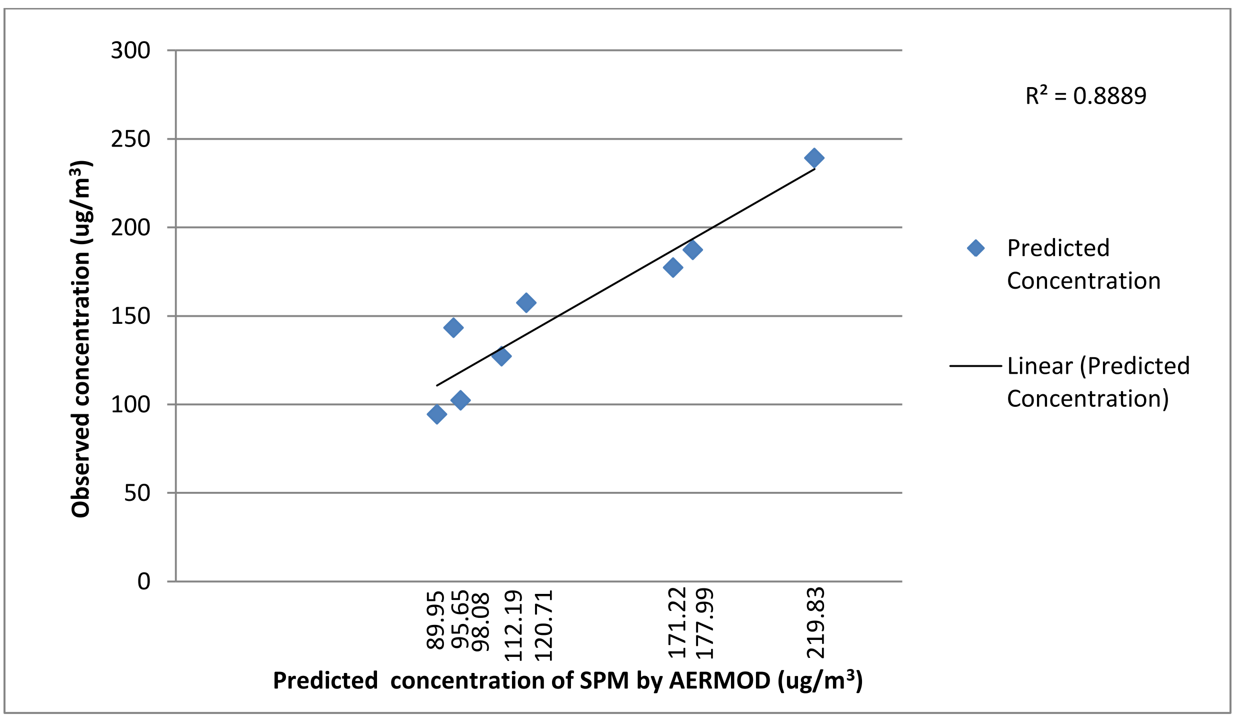

Figure 5.27 SPM predicted (ISCST3) concentration Vs Observed concentration

In Figure 5.26 and Figure 5.27 the coefficient of correlation is 0.867 and 0.887 respectively. The value of R^2 in Figure 5.27 is higher than the Figure 5.26 depicting that that AERMOD predictions are closer to observed concentration than ISCST3 predictions. So, similar to NO_2 and SO_2 results, the predicted values of AERMOD are closer to trend line which indicates that model predictions are close to observed values as compared to ISCST3. These results are similar to the findings done by *Sudarsan et al., (2010)* for predicting the GLC using AERMOD and ISCST3 and comparing with observed value of GLC by field observations. Thus, it can be considered that AERMOD model is more validate in nature, more significant and more accurate than ISCST3.

CHAPTER 6

CONCLUSIONS

In the present study, air quality of Rajpura and other nearby areas was observed due to the upcoming Thermal Power Plant. Using the emission inventory of Thermal Power Plant as the source data, ground level concentrations of SO_2, NO_2 and SPM were estimated by using U.S. EPA approved dispersion models; ISCST3 and AERMOD. The dispersion model results were then compared with each other. Moreover, the model predictions were also compared with the ambient air measurements to determine the accuracies of the models. Ambient air monitoring of NO_2, SO_2 and SPM at 8 receptors were measured from October, 2013 to May, 2014. This real data was used for validation of models. Furthermore, the stack gas emission data of Thermal Power Plant, Hindustan Unilever Pvt. Ltd. and Amrit Vanaspati Pvt. Ltd. was used as the source data in the models to differentiate the effect of Thermal Power Plant alone.

Mean hourly meteorological data for one year period (January 2013 to December 2013) was collected by Weather Monitoring Station and Upper air for the same year was collected from IMD, Pune which was imported to RAMMET View and AERMET View. Based on wind data, population density, topography and other local parameters of study area eight receptors were selected on which maximum incremental GLC of pollutants were 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 the point source shows AERMOD predicted higher incremental concentrations nearer the site than ISCST3 for both averaging periods. As the distance from the site increased, the incremental concentrations and the shapes of the concentration isopleths become similar, though ISCST3 predicted slightly higher concentration then AERMOD. Further, considering all the sources in the study area, the predicted results were almost similar to the results when only source of Thermal Power Plant were considered for predicting the GLC. Thus, based on results it can be concluded that the major source of pollution in the region is Thermal Power Plant.

GLC obtained with two dispersion models were not only compared with each other but also compared with results of ambient air pollution measurements at all the receptors for better model performance. Predictions of both ISCST3 and AERMOD were underestimating the observed ground level NO_2 and SO_2 concentrations at nearby receptors to the thermal power plant which may be attributed to the fact that models can not demonstrate long range transport of the NO_2 and SO_2 at the receptor points located out of these three receptors. Other possible reason might be the building downwash effect which was not included in model runs and that may have caused under predictions for both models *(US EPA 2003).* On the other hand, for SPM predictions of both ISCST3 and AERMOD were under predicting the observed concentration at all receptors. The possible reason could be that models can not demonstrate long range transport of the SPM at all the receptors. Other probable reason could be the low particulate matter emission rate of Thermal Power Plant because the electrostatic precipitators are working with high efficiency.

Overall results of AERMOD seem to be good in correlation graph because the model results and the observed results are located around the trend line as compared to ISCST3. Thus, AERMOD model is more validate in nature hence, the AERMOD seems to be more accurate in predicting the GLCs. Although, ISCST3 and AERMOD generate different results for the same cases, whereas the general pattern of the GLC maps estimated by both models are similar to each other. The similarities were expected because the basic algorithms and assumptions of the models are similar. In brief, it can be concluded that AERMOD model is more valid and accurate than ISCST3 model.

FUTURE RECOMMENDATION

The present study covers the aspects of air quality modeling using EPA approved dispersion models namely; ISCST3 and AERMOD in the study area. The study was done without taking into account the mobile sources. Therefore, further refinement in the study can be carried out by considering the mobile sources in the models run. Furthermore, the study can be extended by assessing the statistical significance of the results by examining the impacts of model options on the model performance with more sensitive monitoring sites or in more modeling domains.

Further studies on predicting and comparing the results of other EPA approved dispersion model like CALPUFF and SCREEN3 can be carried out on the study area.

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 above 70%. Since skipping the meteorological hours with calm conditions may affect the overall performance of the model.

There is limited knowledge on the wind patterns and how the plume behaves during calm conditions at present. Therefore, further studies on plume behavior and wind flow patterns during calm conditions can be carried out. Thus, it is advised that air quality modellers in India should acquire data that is representative of the study domain.

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ANNEXURE I

Revised national Ambient Air Quality Standards (NAAQS) - 2009

S. No	Pollutant	Time Weighted Average	Concentration in Ambient Air		
			Industrial, Residential, Rural and Other Area	**Ecologically Sensitive Area (notified by Central Govt.**	**Methods of Measurement**
1.	Sulphur Dioxide (SO_2), µg/m^3	Annual* 24 hours**	50 80	20 80	- Improved West and Gaeke -Ultraviolet fluorescence
2.	Nitrogen Dioxide (NO_2), µg/m^3	Annual* 24 hours**	40 80	30 80	- Modified Jacob & Hochheiser (Na-Arsenite) -Chemiluminescence
3.	Particulate Matter (<10µ), µg/m^3	Annual* 24 hours**	60 100	60 100	- Gravimetric -TOEM - Beta attenuation
4.	Particulate Matter (<2.5µ), µg/m^3	Annual* 24 hours**	40 60	40 60	- Gravimetric - TOEM - Beta attenuation
5.	Ozone (O_3), µg/m^3	8 hours** 1 hour**	100 180	100 180	- UV photometric - Chemilminescence - Chemical Method
6.	Lead (Pb), µg/m^3	Annual* 24 hours**	0.50 1.0	0.50 1.0	- AAS /ICP method after sampling on EPM 2000 or equivalent filter paper - ED-XRF using Teflon filter

7.	Carbon Monoxide (CO), mg/m^3	8 hours** 1 hour**	02 04	02 04	- Non Dispersive Infra Red (NDIR) spectroscopy
8.	Ammonia (NH_3), $\mu g/m^3$	Annual* 24 hours**	100 400	100 400	- Chemiluminescence - Indophenol blue Method
9.	Benzene (C_6H_6), $\mu g/m^3$	Annual*	05	05	- Gas chromatography based continuous analyzer -Adsorption and Desorption followed by GC analysis
10.	Benzo(a)Pyrene(BaP)- particulate phase only, ng/m^3	Annual*	01	01	- Solvent extraction followed by HPLC/GC analysis
11.	Arsenic (As), ng/m^3	Annual*	06	06	- AAS /ICP method after sampling on EPM 2000 or equivalent filter Paper
12.	Nickel (Ni), ng/m^3	Annual*	20	20	- AAS /ICP method after sampling on EPM 2000 or equivalent filter Paper

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

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

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

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