Chapter 1:- Introduction

1.1 Background

Environmental Pollution level has been an undesirable spin off of a human exercises assumable since the cavemen men initially lit flames. Air contamination is a condition when pollutants are present in such concentration and time that they cause harmful impact on human health. The mathematical expression for pollutant concentration is in terms of mass per unit volume and generally represented as micrograms per cubic meter of air volume. The concentration varies with the type of source and distribution of pollutant with respect to source, topographical and meteorological conditions of the area.

Pollutants are introduced by two ways one is man made acivities which is also called anthropogenic activities and other is natural sources. In urban areas most of the pollution is due to man made activities such as industries, vehicle operation etc Whereas some air pollution is caused by natural occurrences like volcanic eruption, forest fire, sand storm etc.

Suddenly increase in illness and death during air pollution episodes like 1952 London smog which occurred in mid 19^{th} century showed that the air pollution is very harmful to public health. Occurrence of such episodes taken seriously by government and with the help of legislation government tried to reduce pollutant emissions into the atmosphere and it was perceived at that the air pollution was no longer a public health problem (Holland et al. 1979). In the early 1990s, many epidemiologic studies derives that air pollution at lower concentration causes cardiopulmonary disease and mortality (Smaet et al. 2000).

Many epidemiologic studies described that the harmful health effects are mostly associated with small particles ($PM_{2.5}$) which are also called as fine particles. Fine particles are mostly originated in ambient environment from fossil fuel combustion. Studies by seaton et al. 1995 suggested that the particles which have diameter less than 0.1 microns also called as ultra-fine particles ($PM_{0.1}$), can penetrate deep into the region of lungs which causes acute respiratory illness in susceptible person, as well as increasing blood coagulability which may cause heart problems. The predicted total and regional respiratory deposition for light exercise, based on the International Commission on Radiological Protection is illustrated in Figure 1.1 (Hinds 1999). This shows the alveolar deposition in the ultrafine range. It has been investigated that the harmfulness of particulate matter dependent on its chemical composition or on its size than other factors (Harrison et al. 2000).

Particulate matter is defined as the particle or liquid substance in an aerosol. That is a two phase system in which particulate matter and air forms the various types of microscopic particles that remains in the air like particles generated by vehicular combustion, photo-chemically formed particles, and sea salt from the ocean etc. Due to particulate matter there are many effects on the environment such as visibility problem, climate change and adverse health effects. Range of an aerosol in total particles suspended in air is with radius ranging from 0.05 to 15 μm (Dubovik et al., 2002; Shi et al., 2012). The composition of particulate matter is complex and it changes with respect to sources, source strength, and meteorological parameters. Particulate matter contains ions of nitrate and sulpher, trace organics etc.

Particulate Matter ($PM_{2.5}$) is taken in this research study as the pollutant to be monitored because the concentration can be monitored using real time instruments which are easy to handle and the resolution and accuracy are of high.

The most essential parameter in PM is its particle size, particles exist in various different shapes, The size of particles is expressed as the aerodynamic diameter. The size of airborne particles in atmosphere vary from the submicron (<1um) to tens of microns.

Particulate matter is mainly divided in three sizes as coarse mode (or $PM_{10-2.5}$) in which the size of particles range from 2.5 to 10μm, accumulation mode contains particle size ranged between 100nm to 2.5μm , and ultrafine particulate matter are particle having size less than 100nm. All the sizes of particulate matter have their own different property in respiratory deposition, atmospheric formation and deposition mechanisms and particle composition. $PM_{2.5}$ and PM_{10} stands for the particles less than 2.5μm size and 10μm size respectively. Particles greater than 10μm have less attention due to the reason that they do not deposite in nasal region and have less residence time in the atmosphere, while PM_{10} and $PM_{2.5}$ can enter deep into the thoracic region of body due to that it has great interest for air pollution studies and regulatory purposes. Particulate air pollution is a long standing problem in Delhi; recently in the area many studies of fine particle concentrations have been conducted.

Currently in India, PM_{10} and $PM_{2.5}$ are regulated in the National Ambient Air Quality Standards (NAAQS) by Central Pollution Control Board (CPCB).

1.2 Urban areas- the focus of air pollution

The air pollution problem in urban areas has become a part of life and the pollution is increasing day by day with increasing urbanization. The consumption of fossil fuels and their derivatives has been increased with modernization and increased industrial activities, this activity leads to emission of particulate matter and other gaseous air pollutants into the atmosphere. In urban areas most of pollution is due to transportation sector, producing CO, Pb and NO_2. Industries, power plants and the burning of solid waste also augument the pollution load.

Urban areas have individuals which are more susceptible to the immediate effects of air pollution. In 1992, in the conference of the United Nations Conference on Environment and Development (UNCED) created guidelines as well as recommendation in its Agenda twenty one (UN, 1992) on air pollution in cities. One key recommendation was, "… *the establishment of viable air quality management capabilities in huge cities and the establishment of adequate environmental measuring capabilities or surveillance of environmental quality and also the health status of populations*".

Rapid economic growth through urbanization is creating serious air pollution related issues in several areas worldwide. The UN agency has estimated that 1.4 billion urban residents in world's developing countries breathe air in which pollutant concentrations are more than WHO air quality standards (UNEP/WHO, 1992). Urban air pollution episodes are related to sudden incidences of high concentrations of pollutants, which are generally driven by local meteorology, emissions and dispersion conditions (Mayer, 1999). The main source groups responsible for urban air pollution are primarily heavy traffic and industrialization. Over many years, legislation and management have led to marked decrease in the air pollution impacts of industries in several countries. However, there has additionally been a considerable increase in urban pollution from automobiles attributable their increased demand to satisfy transportation needs (Nagendra et al, 2002).

According to Central Pollution Control Board (CPCB) permissible limit of particulate matter for different areas is as shown in Table 1.1:

Table 1.1 National Ambient Air Quality Standards by CPCB

S.N.	Pollutant	Time Weighted Average	Industrial, residential, Rural and Other Area	Ecologically Sensitive Area(Notified By Central Government	Analysis method
1.	Particulate matter (Size less than 10µm) or PM_{10} µg/m^3	Annual 24 hrs	60 100	60 100	-TOEM -Gravimetric - Beta attenuation
2.	Particulate matter (Size less than 2.5µm) or $PM_{2.5}$ µg/m^3	Annual 24 hrs	40 60	40 60	-TOEM -Gravimetric - Beta attenuation

The World Health Organization (WHO) is a agency of the United Nations that is concerned with public health. According to WHO permissible limit of particulate matter is as shown in Table 1.2:

Table 1.2 Air Quality Guidelines (AQG) values for PM by WHO

Type of Pollutant	Annual Average	24-Hour Mean
$PM_{2.5}$	10 µg/m^3	25 µg/m^3 (not to exceeded for more than 3 days/year)
PM_{10}	20 µg/m^3	50 µg/m^3

1.3 Meteorological influence in urban air pollution

Meteorology has a vital role in air pollution studies. In fact, there is a strong seasonality within the meteorologic factors that modulates the air quality levels. The crucial meteorological variables having influence on the levels of the pollutants over urban are wind speed and direction, rain amount and period, air temperature, and relative humidity. Local meteorology that is usually referred to as micrometeorology incorporates a major role in air pollution. The relation between micro meteorology and air pollutants dispersion primary involves wind in broader sense. Wind fluctuations over time and space play a vital role in dispersion of air pollutants. Wind flow in horizontal direction is could be a key parameter in transport of pollutants. A very high wind speed continuously has high air dilution capacity. On the contrary low or gentle wind could favours in accumulation of pollutants. Wind direction mostly influences the pollutants dispersion. Wind direction and wind speed for a given time period in particular period of time is known as windrose that helps to perceive the prevailing wind speed to predict the dispersion of pollutant from a point to area source. Turbulence and atmospheric stability are also very important parameter in dispersion of air pollutants. The urban surface pattern and temperature or solar isolation is the key parameter to determine these two. Thermal turbulence and unstable atmospheric condition always favors the dilution of the emitted air pollutants whereas, mechanical turbulence and stable atmospheric condition do the reverse. Relative humidity often entertains the formation procedure of some secondary pollutant whereas wash out effect of rain scavenges the air pollutants from atmosphere. Thus the analysis of the meteorological observations in the tropical countries like India showed the maximum solar radiation and the highest atmospheric temperature was recorded during the summer season (March–May). It was observed that the velocity of wind was maximum during the months of July followed by August and September. The predominant wind velocity was determined in the northeast monsoon season. Withinn the summer months, the determined wind speed was comparatively lower than those which were in the winter season. The change of relative humidity showed a steep decrease from winter to summer and then a slow increase within the rainy season and remained steady in winter. So, actual monitoring and measuring the meteorological parameters has always been one of the main requirements for good understanding the quality of the atmosphere (Seaman, 2003). The chemical reactions of the pollutants rely on ambient weather and are affected by short- wave radiation, air temperature, wind speed, wind direction and relative humidity (Elminir, 2005). Along with different chemical reactions, dispersion and dilution processes leads to ambient air pollution that presents spatial and temporal variations in concentrations of various substances. The air quality in urban areas has been found related with different combinations of various meteorological factors. Air quality is affected not solely by emission of pollutants however by meteorological parameters also. The source identification of air pollution is a very important for the development of air quality control strategies. Abatement methods might considerably improve the air quality once the sources are identified (Gupta et al., 2004; Wang and Shooter, 2004).

1.4 Health effects associated with PM

Fine particulate matter ($PM_{2.5}$) comes under respirable particles which are small enough to penetrate deep inside the thoracic region of respiratory system. Fine particulate matter ($PM_{2.5}$; particulate matter with diameter less than 2.5 μm) are receiving attention for its potential toxicity and role in visibility and health problems. The health effects of particulate matter is due to exposure over short term (hours, days) and long term (months, years) each includes:

• Respiratory and cardiovascular morbidity, like asthma, respiratory symptoms and an increase in hospital admissions;

• Mortality resulting from cardiovascular, respiratory diseases and lung cancer. (WHO 2013)

The people with pre-existing lung or heart disease, as well as elderly people and children are most vulnerable to such effects. For example, PM exposure affects lungs development to children, as well as chronically reduced lungs growth rate including reversible deficits in lung functioning and a deficit in long-term lung function (WHO fact sheet 2011). There is no evidence of a threshold below which no adverse health effects occur. The exposure is ubiquitous and involuntary, increasing the significance of this determinant of health. (WHO 2013)

At present for the effect of particles at the population level there is not enough evidence to identify differences with effect of different chemical compositions or emanating from various sources (Stanek et al. 2011). But, the evidence for the hazardous nature of combustion related particulate matter (from mobile and stationary sources both) is more consistent than for particulate matter from other sources (WHO workshop 2007). The black carbon part of $PM_{2.5}$, results from incomplete combustion, has contribution to detrimental effects on health as well as on climate. Many components of particulate matter that are attached to black carbon are seen as responsible for the health problems, for example the organics such as PAHs that are known as carcinogens and are toxic to the cells, as well as metals and inorganic salts. The exhaust comes from diesel engines (mostly consisting of particles) was classified by the International Agency for Research on Cancer (IARC) as carcinogenic (Group 1) to humans (IARC 2012). This list of IARC includes some PAHs and related exposures, as well as the household use of solid fuels (IARC 2010 vol. 92, 95).

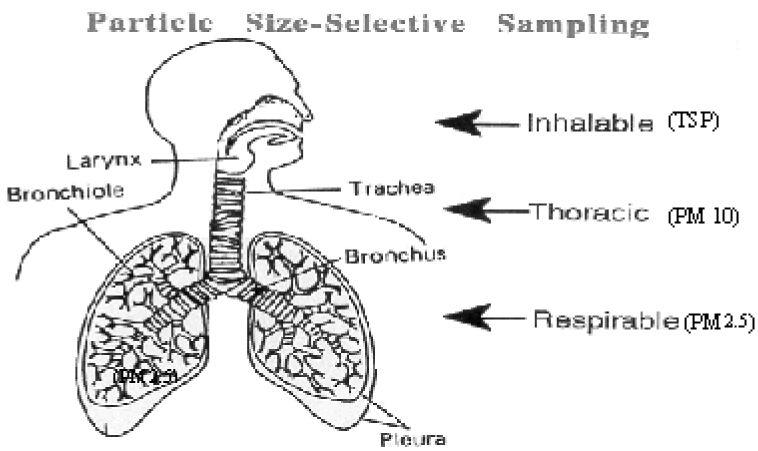

Figure1.1: - Breathing zones of Inhalable, Thoracic, and Respirable dust particles.

1.6 Sources of Particulate Matter

- Particles may either be directly emitted in the air which are referred to as primary particulate matter or be produced in the atmosphere from gaseous predecessors such as sulfur dioxide, oxides of nitrogen etc. called as secondary particles. Primary particulate matter and the precursor gases can have both manmade and natural sources.
- Man made sources embrace engines (diesel and petrol both), solid-fuel (coal, lignite, heavy oil etc.) combustion for energy production in households and industry level, other industrial activities (building, mining, manufacturing of cement, ceramic and bricks), and road traffic (erosion of the pavement and abrasion of brakes and tyres).
- Secondary particles are formed in the atmosphere by chemical reactions of gaseous pollutants. They are byproducts of atmospheric transformation from NO_x (mainly emitted by traffic and some industrial processes) and SO_2 results from the combustion of sulfur-containing fuels. Secondary particles are mainly found in fine particulate matter.
- Soil and dust re-suspension is also a source of particulate matter, particularly in arid areas or during episodes of long-range transport of dust.

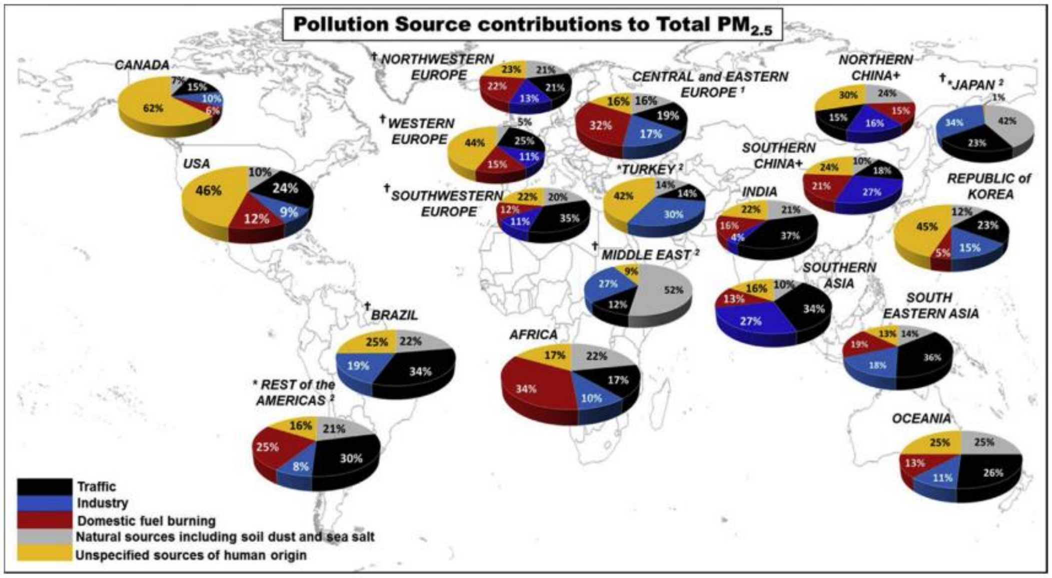

Figure 1.2 Pollution sources contribution to Total $PM_{2.5}$ (Federico et al. 2015)

1.7 Global scenario of $PM_{2.5}$ pollutant

Due to the less ground-level data for particulate matter, the assessment of population exposure at country level has been done with remote sensing combined with modelling and existing surface measurements.

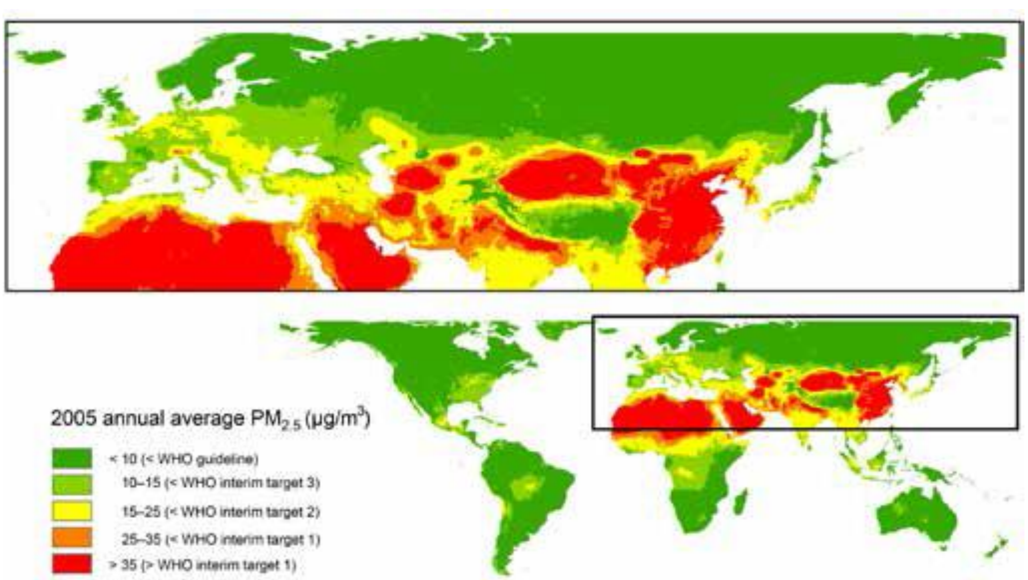

Figure 1.3: -Estimated 2005 annual average $PM_{2.5}$ concentrations (µg/m3), presented according to the WHO AQG and interim target values *Source:* Michael Brauer et al., 2012; WHO 2013.

Recent estimates have been published for fine particulate matter ($PM_{2.5}$) concentrations all over world using this technology as part of the Global Burden of Diseases, Injuries and Risk Factors Project (Brauer et al., 2012; WHO 2013) shown in Fig. 1.3.

1.8 Indian scenario of $PM_{2.5}$ pollutant

Particulate matter ($PM_{2.5}$) concentration for annual average for different cities is shown in fig 1.4. The higher concentrations are in Ludhiana and lowest is in Kochi.

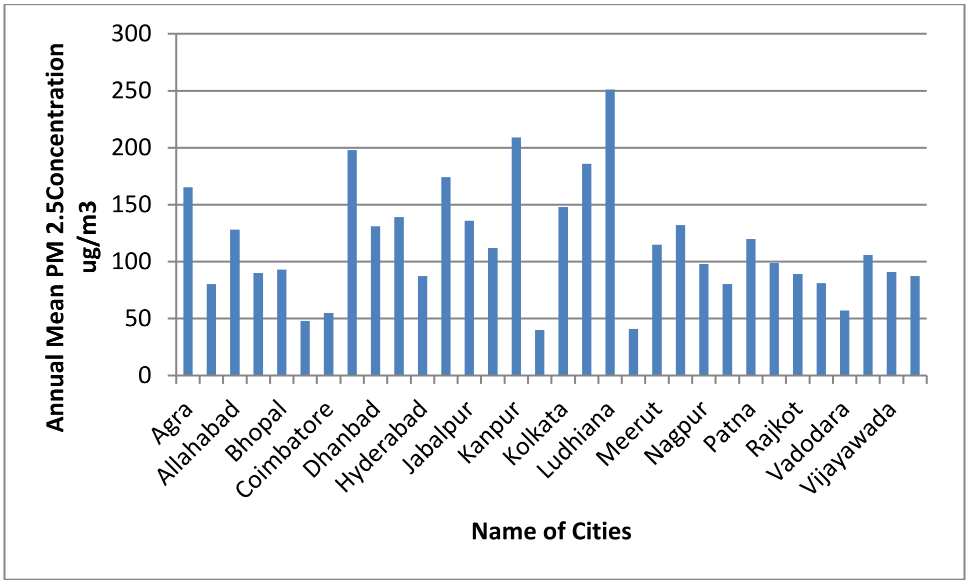

Figure 1.4 Annual Mean $PM_{2.5}$ concentration of cities of India as per WHO (Outdoor Air Pollution Database 2011)

1.9 Line source emission modeling

Line source emission modeling is an important tool in control and management of vehicular exhaust emissions (VEEs) in urban environment. The US Environmental Protection Agency and numerous other research foundations have built up various line source models (LSMs) to describe temporal and spatial distribution of VEEs on roadways.

The vast majority of these models are either deterministic or statistical in nature. Line source emission modelling (LSEM) is a critical tool in screening of VEEs and helps in control and management of urban air quality. The CALINE 4 model has good performance than other LSMs and is widely used to predict near road motor vehicle emissions (Benson, 1992). CALINE 4 model is a line source air quality dispersion model that is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion in the vicinity of roadways.

CALINE 4 utilizes a series of equivalent finite line sources to represent the road segment. The aggregate street systems is separated into limited number of components, at that point every component is modeled as an equivalent finite line source positioned normal to the is displayed as a proportionate limited line source situated ordinary to the wind direction and centered at the element midpoint. A local X-Y coordinate system aligned with wind direction and originating at the element midpoint is characterized for each element (Majumdar et al., 2008). In an investigation CALINE 4 model was selected as the base model for Bangalore city to predict $PM_{2.5}$ at traffic intersection. Deterministic LSEM approach is the most logical and traditional approach for the prediction of air pollution concentrations, yet it is not free from limitations. The prediction capability of deterministic models depends on the condition fulfilling the simplifying assumptions, which are made in the model formulation (B. Santhaveerana, 2015).

CALINE4 is the most recent version of the CALINE model series developed by the California Department of Transportation. It embeds the concept of mixing zone and uses modified Gaussian distributions (Benson, 1984). CALINE4 uses a series of equivalent finite line sources to represent the road segment, and models the whole region of finite line sources as a zone with uniform emissions and turbulence.

Chapter 2: - Literature Review

2.1 Particulate Matter

Particulate pollution in urban area atmosphere has became a matter of concern now a day. Different kind of natural as well as anthropogenic activities are contributing a large amount of particulate matter into ambient air. A number of research works are performed on particulate matter in several Indian cities like Delhi, Kolkata, Dhanbad, Jharia, Lucknow, Mumbai, Chennai, Visakhapatnam etc. in our nation as well as in abroad like in Taiyuan, Kathmandu , Guiyang, Dhaka, Pakistan and Italy etc. All these research works reflects that these particulate matters are comprised of trace amount of heavy metals like Pb, Cd, Cr, Mn and other inorganic ions like Na^+, K^+, F^-, SO_4^{2-} and Cl^-. These secondary air pollutants are also found to be dependent on the prevailing meteorological condition. It is noticed that the atmospheric Pb is in decreasing trend now a day due to phase out of leaded gasoline in cities. Cd and Mn both are originated primarily from industrial origin and transportation activities etc. However, a few mentionable works are as follows.

2.1.1 National level

According to Kushwaha et al.,(2012) suspended particulate matter pollution in air of most cities is high especially in Delhi. Khare et al., (2010) stated that particle pollution has rapidly become a severe problem due to rapid industrialisation and urbanization in the last two decades in India. According to Tiwari et al., (2013), Delhi has heavy movement of vehicular traffic, a number of studies have analyzed air concentration data for Delhi and vehicular growth has resulted in significant rise in levels of total particulates. According to Kushwaha et al., (2012); Pramod et al., (2014) vehicular emissions are ground level sources of air pollution therefore they have maximum impact on the general population.

Goyal and Sidhartha (2002) calculated the monthly mean suspended particulate matter concentrations. The highest concentration is reached in November (465.68 µg/m3) and lowest in August (150.07 µg/m3). Due to the presence of low–level ground-based inversions in winter, high concentration of suspended particulate matter was found in this season.

Balachandran et al. (2000) had examined the concentration of composition of PM_{10}, the thoracic fraction of the atmospheric particulate matter in Delhi. PM_{10} particulates were subdivided into two fractions, coarse (2.1–10 mm) and fine (2.1 mm). The mean value of PM_{10} obtained at Daryaganj for four months was observed as 658.45±231.2 µ g/m^3 which was 1.45 times higher as compared to JNU (454.77±106.2 µg/m^3) and 1.1 times higher as compared to Moti Nagar (552.8±225.7 µ g/m^3) in Delhi. All these values were found to be exceeded the national standards (150 µ g/m^3 for industrial area and 100 µ g/m^3 for residential area for 24 h) for PM_{10} for both industrial and residential area as specified by Central Pollution Control Board of India.

The monthly mean suspended particulate matter (SPM) concentrations reached the highest (465.68 µg/m^3) in November and the lowest (150.07 µg/m^3) in August**.** The high concentration of SPM was obvious in winter due to the presence of low– level ground-based inversions. However, the high winds and convective atmospheric conditions in postmonsoon and premonsoon seasons encouraged dispersion of particulates; on the other hand, the major emission sources of SPM in Delhi were power stations and industries (Goyal and Sidhartha, 2002).

Road ambient air pollution status along Dhanbad- Jharia road was studied by Jain and Saxena (2002). The variation in the SPM concentration were found as 351.12 to 411.41 µg/m^3 in monsoon and 536.88 to 602.02 µg /m^3 in winter season. According to Verma et al. (2003) the air was contaminated maximum with both gaseous and particulate matter in Lucknow. It was observed that RSPM level was higher than the permissible limit at all sites and ranged between 150 -945 µg/m^3. The highest level of RSPM was found at the site with the maximum traffic density (6723 vehicles/h) while the least RSPM was found at the site with minimum traffic density (52 vehicles/h).

Respirable suspended particulate matter (RSPM) and total suspended particulate matter (TSPM) in Chennai was studied by Pulikesi et al. (2006). It was found that the TSPM values were exceeded the National Ambient Air Quality Standards (NAAQS) at Koyambedu, Mandaveli, Taramani and Vallalar Nagar study area. Suspended particulate matter (SPM) was also measured by Reddy and Ruj (2003) in the Raniganj- Asansol area in West Bengal, India. Results of the investigation indicated that the 95th percentile value of SPM levels exceeded the limits (200 μg/m^3) at different sites and was found within the limit of 500 μg/m^3 at one region. It was also observed that monsoon experienced the lowest SPM levels at the four monitoring sites, which was because of the wash-out of dust by intermittent precipitation. It was also observed that in general the SPM levels tended to decrease with increasing relative humidity. Another important fact was revealed by them that SPM concentration was higher during the day than during the night. This was mainly attributed to the hectic industrial, mining and other community activities, as also to increased vehicular traffic during the day period. SPM values were found to exceed the prescribed standards in winter at most of the sites and in summer at few sites in Visakhapatnam (Reddy et al., 2004).

Measurements of the aerosol number concentration and the PM_{10} mass concentrations of urban background aerosols in different seasons were performed by Monkkonen et al. (2004) in New Delhi 2002, including the simultaneous measurements of NO_2, SO_2 and CO concentrations. The results indicated an interesting relationship between the aerosol number and the PM_{10} mass concentrations. The number concentration increased with the mass concentration up to 300 μg/m^3. Diurnal mean of NO_2 concentrations varied from 50 μg/m^3 (2- 6 am) to 79 μg/m^3 (6-10 pm) with a maximum value observed in November (170 μg/m^3) and a minimum in March (6 μg/m^3). NO_2 concentrations were found usually highest in the evenings (6-10 pm), which could be explained by the traffic peak hour after 6 pm, but also by the use of natural gas as fuel in cooking ranges.

Kumar and Joseph (2006) had worked on $PM_{2.5}$ and PM_{10} to understand the fine particle pollution in compliance with ambient air quality standards in Mumbai. The average $PM_{2.5}$ concentration at ambient and at Kerbsite was 43 and 69 μg/m respectively. The correlation coefficients between $PM_{2.5}$ and PM_{10} at ambient and at Kerbsite were 0.83 and 0.85 respectively thus indicating that most of the $PM_{2.5}$ and PM_{10} were released from similar sources. PM_{10} levels exceeded the Central Pollution Control Board standard during winter season.

Gupta et al. (2008) had dealt with air quality monitoring in an urban region of Kolkata, consisting of residential, commercial and industrial sites having high population density and pollution. Daily average PM_{10} concentrations exceeded quite a number of times the NAAQ standards. Approximately 85 % of the monitored PM_{10} data at residential area and 70 % at industrial area exceeded NAAQS. The observed daily average PM_{10} concentrations were 140.1 $\mu g/m^3$ and 196.6 $\mu g/m^3$, respectively at residential and industrial sites, while 8 h average concentrations of PM_{10} at commercial site were 131.3 $\mu g/m^3$.

The respirable particulate matter and total suspended particulate matter (TSP) concentrations in ambient air in Tuticorin, India, were preliminarily estimated by Sivaramasundaram and Muthusubramanian (2010). Both the RPM and TSP levels were found well below the permissible limits set by the US Environmental Protection Agency. The RPM concentrations ranged between 20.9 and 198.2 $\mu g/m^3$, while the TSP concentrations varied from 51.5 to 333.3 $\mu g/m^3$ during their study period.

2.1.2 International level

According to Riediker et al., (2004) with increase in traffic intensity mass concentrations of particles have been observed to increase. The majority of fine particles originate from wear of tire and brake systems, exhaust emissions.

Onat et al., (2013) found that the $PM_{2.5}$ concentrations inside the metro–bus and car (AC fan off and RC on) were considerably lower than those observed for walking. The reason for the high $PM_{2.5}$ levels for walking could be the suspension of particles because of the movement of wind.

According to Artíñano et al., (2004) road transport is known for one of the main sources of urban pollution, although other sources linked to combustion processes, such as domestic, residential and institutional heating, also contributes to a significant pollutant emissions in urban areas.

Wrobel et al. (2000) investigated that in cities, motor vehicle is the main source of PM emission contributing to more than 50% of the total PM emissions.

Studies showed that the most of ambient air particles in urban area are of anthropogenic origin Dolinoy et al., (2004); Heal et al., (2005); Song et al., (2006); Quan et al., (2008); Tang et al., (2009).

In comparison to developed countries, developing countries worldwide have more anthropogenic (i.e. manmade) air particle pollutants, such as urban smog and dust storms Davis and Guo, (2000); Zhao et al., (2004); Yuan et al.,(2008); Tang et al., (2009) and it is due to he rapid economic development and intensive human land use activities in urban areas Tang et al., (2009).

Aerosol number concentration and the PM10 mass concentrations of urban background aerosols were measured in different seasons New Delhi 2002, including the measurements of NO2, SO2 and CO concentrations at the same time. The results showed relationship between the aerosol number and the $PM_{2.5}$ mass concentrations. The number concentration was increased with the mass concentration up to 300 μg/m Monkkonen et al., (2004).

Particulate matter in terms of environmental pollutant preserves a quality which makes it air pollutant problem Pryor et al., (1996); Calcagni et al., (1992); Al Jallad et al., (2013); Pramod et al., (2014)

According to Adams et al., (2001); Kam et al., (2011); Cheng et al., (2012); Pramod et al., (2013), traffic micro environment has recently having particular attention because $PM_{2.5}$ concentration is generally higher than ambient levels on which air quality standard is found. Particulate matter is a major component of photochemical smog and influences surface albedo by decreasing the amount of heat reaching the surface Seinfeld and Pandis (2006). Particulate matter emissions in the urban areas depends on vehicle type, fuel type and engine, cold start and hot start, speed of the vehicle, driving cycle and silt load Sadler et al., (1996) and Pramod et al., (2014).

Clarke et al. (1999) had found that in urban conditions, small aerosol particles were mostly emitted from combustion processes, i.e. car engines and industry. Urban aerosols had a higher proportion of vehicular (and possibly industrial) emissions, which were in very fine size range.

The larger particles correspond to the effects of human activities including road dust raised by vehicular motion, building activities and industrial emissions. According to Vakeva et al. (1999), Mazzera et al. (2001), Querol et al. (2001), Viana et al. (2006), Adachi and Tainosho (2004) the particulates were directly emitted into the atmosphere through natural and manmade (anthropogenic) processes including transportation, fuel combustion in stationary sources, industrial processes, land cleaning, wild fires and solid waste disposal. It was also found that from the particle formation studies, it could be assumed that the majority of the submicron particles were due to primary emissions from traffic, or at least particles were formed very close to the sources (car engines) of precursor gases (Vakeva et al., 1999).

Giri et al. (2006) had measured the ambient particulate matter concentrations (PM_{10}) at a network of six air monitoring stations in Kathmandu valley during the years, 2003 to 2005. The study revealed that particulate concentrations measured were persistently higher at air sampling sites representing roadside areas compared to the background sites. The highest daily average PM_{10} mass concentration (633 µg/m^3) for the study period was recorded at Putalisadak air monitoring station in the year 2005. Within the Kathmandu valley daily 24-h average PM_{10} ranged from 7 µg/m^3 (Matsyagaon in the year 2004 and 2005) to 633 µg/m^3 (Putalisadak in the year 2005). The lowest and highest average annual concentration during the study period was found 47.78 µg/m^3 and 199.80 µg/m^3 respectively at Matsyagaon and Putalisadak air-monitoring sites. It could be assumed that the difference in the observed concentrations can mostly be attributed to the traffic. Due to the rapid growth of industrial activities, population and traffic density, people in Kathmandu were facing serious air pollution problems.

Mulaku and Kariuki (2001) outlined the air quality management capabilities of developed and developing nations and found that in developing nations, especially those in Africa, such capabilities were either absent or only rudimentary; the situation in Kenya was given as an example. They studied to determine the spatial distribution of TSP in Nairobi, Kenya’s capital city. A map showing the distribution had been produced, probably the first of its kind for the city, which showed that the levels of TSP in most of Nairobi were much above the average recommended by the World Health Organization.

A field study was carried out in central Italy on characterising atmospheric particulate matter (PM_{10} and $PM_{2.5}$) from the point of view of the chemical composition by Perrino et al. (2007). An evaluation of the sources of PM and an identification of possible reliable tracers were obtained using a chemical fractionation procedure in their study. Total concentrations and speciation of metals had been studied in TSP of Guiyang by Wu et al. (2008) from April 2006 and January 2007 in PR China. The total average concentrations of five sites were found as 263 and 75.5 µg /m^3 for SPM and PM_{10} respectively in greater Dhaka Salam et al. (2008).

Ali and Athar (2008) had investigated the air and noise pollution at selected sites along three sections of National high way in Pakistan to assess the enormous impact of transportation system on ambient air quality. Particulate matter (PM_{10}) was found very high in all the locations of three sections. By comparing the data with specified limits of USEPA ambient air quality standards, the concentrations were found high at all the locations and were in range of 123- 434 µg/m^3 against USEPA ambient air quality standards of limit 150 µg/m^3. At all the locations particles of soil were very fine and proportion of clay was higher that could also be the reason of high value of PM_{10}.

Wang et al. (2008) had worked to define the air quality during the Olympic Games from August 7 to September 30 in 2007 in Beijing. The results showed that the average daily concentration of PM_{10} during observation was 0.19 mg/m^3. The concentration of PM_{10} was much higher than the values of the standard. Perrino et al. (2008) had worked on monitoring the inorganic constituents of urban air pollution in the Lazio region in Central Italy. The results showed a major impact of primary anthropogenic pollutants on traffic stations and a homogeneous distribution of secondary pollutants over the regional area. An evaluation of the sources of PM and an identification of possible reliable tracers were obtained using a chemical fractionation procedure.

Xie et al. (2009) characterized the ambient particulate pollution, samples of particulates with aerodynamic diameter less than 10 µm (PM_{10}). Iron-rich particles, gypsum, cement particles, silicon sulphide particles, ammonium chloride, potassium sulphate etc were analysed in this research. The majority of the particles were seemed to originate from coal combustion, which conformed to Taiyuan’s industrial structure. Coal combustion was the main source of particles in Taiyuan air, as evidenced by the abundance of the characteristic coal-burning-related particles.

Traffic-related air pollutants were monitored near major roads at 10 sites in Japan by Naser et al. (2009). Suspended particulate matter (100 % cut-off aerodynamic diameter at 10 mm), $PM_{2.5}$ (50 % cut-off aerodynamic diameter at 2.5 mm), and black carbon, from which elemental carbon (EC) content was calculated, were instantaneously and continuously monitored at four stations at various distances (about 5, 35, 70 and 150 m) from each of the target roads. They compared the observed concentrations with concentrations calculated by means of the conventional Gaussian plume model. By assuming that the emission factors of EC was proportional to that of PM and by using the emission factor of NOx, estimated the emission factor of EC by evaluating the ratio. Good agreement between the observed and estimated ratios was obtained with a proportionality constant (EC/PM) of 0.4, indicating that the emission factor of EC was 0.4 times the PM

2.2 CALINE4 Model

The CALINE4 model is widely used to predict near-road vehicle emissions. This model has been tested and validated for predicting concentrations of several vehicle-emitted pollutants nearroad under certain conditions, such as CO, oxides of nitrogen (NOx), and additional gases. B. Santhaveerana Goud et al. (2015)

Hence, an attempt was made using CALINE 4 model to estimate particulate matter ($PM_{2.5}$) concentrations at traffic intersection namely, Central Silk Board, Bangalore. Traffic analysis was conducted between 6:00AM to 10:00PM. Peak flows of traffic were recorded between 8.00AM to 12.00 Noon and 4.00PM to 8.00PM. Estimated PM2.5 concentrations using CALINE 4 was ranged from 121.3µg/m3 to 403.7µg/m3. Maximum concentrations were observed on Monday's and Friday's. The estimated concentrations of $PM_{2.5}$ were compared with measured concentrations of KSPCB, Bangalore. Based on the comparative test (t-test) results the performance of CALINE 4 model for prediction of $PM_{2.5}$ concentration is valid and can be accepted. The values of NMSE, FB, and GMB were well within the prescribed limits. Hence, CALINE 4 model is a useful tool to predict the pollutant concentrations at traffic intersections B. Santhaveerana et al. (2015).

Loranger et al. (1995) showed that CALINE4 predicted near-road CO concentrations well, but under-predicted manganese (Mn) concentrations. Broderick et al. (2005) examined

CALINE4's performance of modeling transportation-related CO for a free-flowing motorway and a periodically congested roundabout in Ireland and concluded that CALINE4 functioned well under stable atmospheric conditions but performed poorly under low wind conditions. Marmur and Mamane (2003) showed that CALINE4, together with emission factors predicted by COPERT III, is suitable for near-road NOx concentration prediction in open urban and rural sites in Israel, though this conclusion may not be extended to dense urban center locations.

Levitin et al. (2005) showed that CALINE4 performed well for near-road NOx and nitrogen dioxide (NO2) concentrations prediction. Kenty et al. (2007) showed CALINE4 predicts NOx concentration well, but under-predicts NO_2 concentrations probably due to assumptions imbedded in the model.

Jones et al. (1998) showed that CALINE4 predicts well for daytime 12-hour average concentrations of transportation related benzene, toluene, ethylbenzene and xylene in urban areas. Broderick and O'Donoghue (2007) examined CALINE4's capability in predicting transportation related emissions of seven inert gases – n-Pentane, Iso-pentane, Ethene, Propene, 1,3-Butadiene, Acetylene and Benzene under low wind speeds and showed that CALINE4, together with emission factors predicted by COPERT III, gives good long-term estimations but underestimates higher percentile concentrations when evaluating short-term conditions.

CALINE4 has also been tested in predicting particle concentrations in two studies. Gramotnev et al. (2003) used a modified version of CALINE4 to estimate motor vehicle emission factors of fine and ultrafine particles near a busy road in the Brisbane area in Australia. Employing the resulting emission factors, they found that the CALINE4 model results matched the observed rate of dispersion with distance from the road well.

Yura et al., 2007 explores the range of CALINE4's PM2.5 modeling capabilities by comparing previously collected PM2.5 data with CALINE4 predicted values. Two sampling sites, a suburban site located at an intersection in Sacramento, CA, and an urban site located in London, were used. Predicted concentrations are graphed against observed concentrations and evaluated against the criterion that 75% of the points fall within the factor-of-two prediction envelope. For the suburban site, data estimated by CALINE4 produced results that fell within the acceptable factor-of-two percentage envelope. A reverse dispersion test was also conducted for the suburban site using observed and calculated emission factors, and although it showed correlations between the observed values and CALINE4 predicted values, it could not conclusively prove that the model is accurate at predicting PM2.5 concentrations. Although the results suggest that CALINE4 PM2.5 predictions may be reasonably close to observed values, the number of observations used to verify the model was small and consequently, findings from the suburban site should be considered exploratory. For the urban site, a much larger data set was evaluated; however, the CALINE4 results for this site did not fall 75% within the factor-of-two envelope. Several factors, including street canyon effects, likely contributed to an inaccuracy of the emission factors used in CALINE4, and therefore, to the overall CALINE4 predictions. In summary, CALINE4 does not appear to perform well in densely populated areas and differences in topography may be a decisive factor in determining when CALINE4 may be applicable to modeling PM2.5. For critical transportation projects requiring PM2.5 analysis, use of CALINE4 may not be optimal because of its inability to produce reasonable estimates for highly trafficked areas. Additional data sets for CALINE4 analysis, particularly in urban environments, are required to fully understand CALINE4's PM2.5 modeling capabilities.

2.3 Health Effects due to Particulate Mattter

WHO 2013 in its report said that $PM_{2.5}$ is a stronger risk factor than the coarse part of $PM_{2.5}$ (particles in the 2.5–10 µm range). It is estimated that around 3% of cardiopulmonary and 5% of lung cancer deaths are attributable to PM globally.

Schwartz et al., (1996); Borja-Aburto et al., (1998); Sharma et al.,(2013) had also stated that $PM_{2.5}$ has stronger health effect than PM_{10}.

According to Sharma et al., (2007) the particle size is important in respect of deeper penetration into the lungs. Fine particles are also carrier of toxic air pollutants including heavy metals and organic compounds. The fine particles ($PM_{2.5}$ and PM_1) are more harmful to human health than PM_{10} and they act as carrier of toxic substances Ostro et al. (2006).

According to Beelen et al., (2008); Pope et al., (2004), (2002); Chen et al., (2005); Crouse et al., (2012); Dockery and Pope, (1993); Katanoda et al., (2011); Laden et al., (2006); Lepeule et al., (2012); Miller et al., (2007); Ostro et al., (2010); Puett et al., (2011), (2009); Sabit et al., (2014) cohort studies have identified consistent associations between ambient $PM_{2.5}$ and cardiorespiratory morbidity and mortality.

Airborne solid particulate matter is a major contributor of urban air pollution sources. Respiratory diseases, such as asthma, pneumonia, and bronchitis may be caused due to high concentrations of fine particles in the air Owens (1991); Houssaini et al., (2007); Babin et al., (2008); Tang et al., (2009).

Long term exposure to high concentration of air particulate pollution increases probability of human lung cancer and cardiorespiratory mortalities Schwartz, 1994; Goldberg et al., (2001); Pope III et al., (2002); Solomon et al., (2003); Kan et al., (2004); Kim et al., (2009); Tang et al., (2009).

During their research study Yim & Barrett, (2012) applied a multi scale air quality modeling system to assess the impact of combustion emissions on air quality of UK: epidemiological evidence quantitatively related $PM_{2.5}$ exposure to risk of early death.

Airborne particulates can be inhaled into the human lungs, where they are absorbed by blood, and consequently are responsible for the harmful health effects Shi et al., (2012).

Shi et al., (2012) studied that the significance of adverse effects on our health depends on the size and composition of particulates.

Particles less than 2.5 μm ($PM_{2.5}$) can penetrate deeper into the air sacs of human lungs and therefore cause the greatest harm to human health Chan et al., (2000); Shi et al., (2012).

Cohen et al., (2005); Ostro et al.,(2008); Peng et al ., (2008); Shi et al., (2012) stated that particulate matters affects pulmonary function and can thereby cause respiratory diseases and adverse effect on public health and even premature death.

Ostro, (1993); Dockery and Pope, (1994); Tony, (1995); Verhoeff et al., (1996); Tsang et al., (2008); Otmar et al., (2010) said that long term exposure to high levels of respirable particulate matter is closely associated with an increase in respiratory problems, hospital admissions and mortality.

Chapter 3: -Research Methodology

3.1 Methodology

The study is conducted in megacity Delhi. Fine Particulate matter ($PM_{2.5}$) concentrations is measured at different locations of Delhi classified as residential areas. For this study, Haz-Dust sampler (EPAM-5000) has been used monitor the $PM_{2.5}$ concentrations at various locations. This instrument is light weighed, easy to handle and operates as well as effectively for a given time resolution.

CALINE 4Model is applied using the concentration found through instrument in Delhi. Haz-Dust Model EPAM-5000 conducted real-time concentrations calculations at every one minute interval. For modeling average of 1 hrs concentration of $PM_{2.5}$ is taken. The data from the instrument were then downloaded to a laptop and saved in MS excel format. The computer based program of CALINE4 is the most recent version of the CALINE model series developed by the California Department of Transportation. Input ambient data were taken from www.cpcb.nic.in and mixing height data were taken from httpenvitrans.commixing-height-data-india.php. It embeds the concept of mixing zone and uses modified Gaussian distributions (Benson, 1984). CALINE4 uses a series of equivalent finite line sources to represent the road segment, and models the whole region of finite line sources as a zone with uniform emissions and turbulence. CALINE 4 is used to predict the concentration and Geometric Mean Bias, Fractional Bias, Normalized Mean Square Error, Correlation Coefficient is used to verify the performance of Caline 4 results.

Selection of sites to fulfill objectives

⇩

Observation of traffic volume data, fine particulate matter ($PM_{2.5}$) concentration

⇩

Collection of meteorological parameters

⇩

Predicting $PM_{2.5}$ concentration
using CALINE 4

⇩

Validating the predicted values
using NMSE, FB, GMB, correlation values.

3.2 STUDY AREA

3.2.1 General

The data was collected from different locations in Delhi. The locations were choosen so as to represent different land use pattern within Delhi like Residential, Commercial, Silence and Heavy Traffic zone.

3.2.2 Identification of Locations

To measure the concentration of fine particulate matter, the first task was site selection. Therefore, after performing several surveys of different areas in Delhi, nine sites were selected where the continuous uninterrupted flow of vehicles were occurring. The sites selected were Karol Bagh, Uttam Nagar, Punjabi Bagh, Janpath, Laxmi Nagar, Madhuban Chowk. The selected locations and their land use pattern are depicted in Table 3.1. The map of Delhi showing the selected locations for field studies are presented in Figure 3.1.

Table 3.1: Selected locations and their land use pattern.

S.N.	Location Name	Land Use Pattern
1.	Madhuban chowk	Commercial and Residential
2.	Laxmi Nagar	Commercial and Residential
3.	Karol Bagh	Commercial and Residential
4.	Punjabi Bagh	Commercial and Sensitive
5.	Uttam Nagar	Commercial and Residential
6.	Janpath	Commercial

Fig 3.1: Map of Delhi Showing Identified Locations for Study.

3.3 Characteristics of instruments: -

This instrument is light in weight, handling is easy and operation is effective for a given time resolution. The Haz-Dust EPAM-5000 is a high sensitivity real-time particulate monitor developed for ambient environmental as well as indoor air quality applications. This unit combines the filter techniques with real-time monitoring methods.

The equipment use the principle of light scattering near forward of an infrared radiation to immediately and continuously measure the concentration in mg/m^3 of airborne dust particles taken by filter. This principle uses an infrared light source positioned at a ninty degree angle from a photo detector. As the airborne particles enter the infrared beam, they scatter the light.

The amount of light received by the photo detector is directly proportional to the aerosol concentration which gives the concentration. A unique signal processes internally and compensates for noise and drift. This allows high resolution, low detection limits and excellent base line stability.

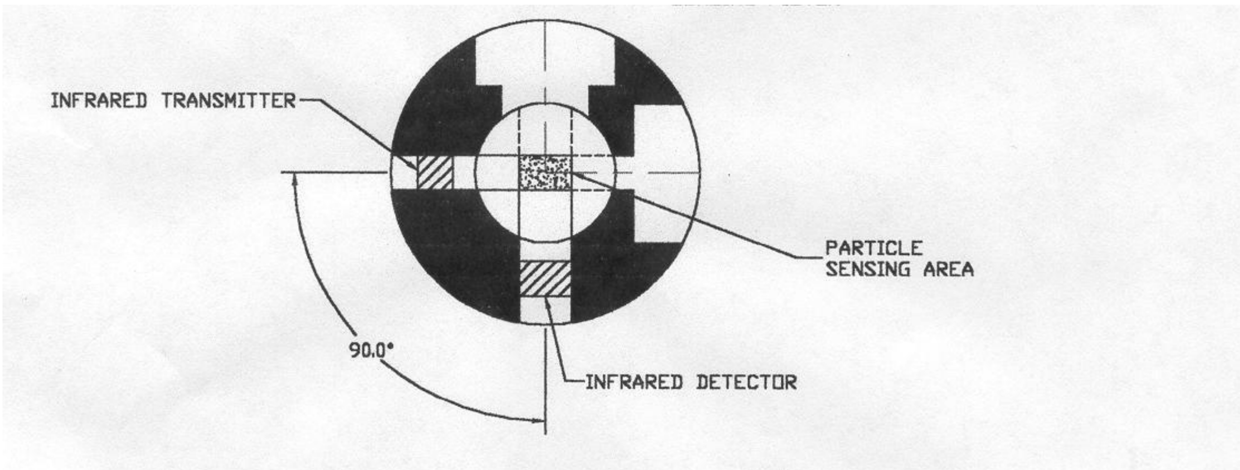

Figure 3.2: - The principle of near-forward light scattering used in the Haz- Dust..

The instrument provides a combination of features to provide superior data quality, easy in use, and flexible to the user.The equipment shows Real-time display of Particulate concentration levels of $PM_{1.0}$, $PM_{2.5}$, PM_{10}, or TSP as filter of given size is used in the equipment and Store data by location code. It has air sampling pump built inside which inhale the ambient air. The sensor is Auto purging. The instrument has on-screen programming of sampling and data storage parameters with real-time clock and a user selectable audible alarm data can be managed to store in intervals of 1 second, 1 minute, 10 second, or 30 minutes. Memory storage of up to 21,600 data points, which can be, distributed into a maximum of 999 location files which makes is very easy to use for long time with various locations. Dust Comm Pro software which available with the instrument offers comparative graphical and statistical analysis.

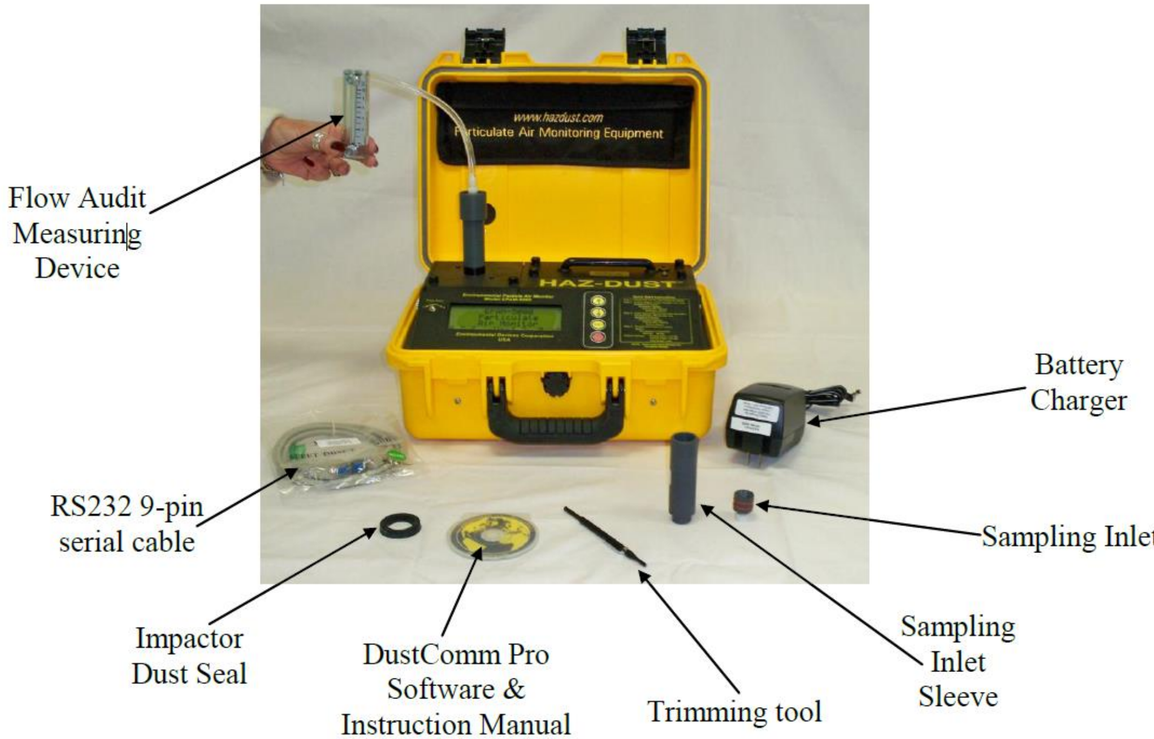

Figure 3.3: - Haz-Dust EPAM-5000 with its accessories.

3.4 Determination of performance of model:-

Results obtained by Caline 4 model is evaluated by 4 methods which are described below. Inferable from an absence of experience and inadequate data, building up stringent numerical standards for model evaluation would be improper. All things considered, increasing amounts of information as is depicted above are becoming available on performance statistics. Kumar and Gudivaka (1990) have discussed in detail the statistics significant to model evaluation and have applied it to heavy gas models. Similarly the case of Kumar *et al* (1993) who have used statistical tools to check the prediction of lower flammability distances. There are three steps that can be used to determine which model performs superior to contending models. The initial phase in the process is a screening test to eliminate models that fail to perform at an adequate level. The second step is connected to models that pass the first screening test and includes the assurance of trust in model results. The last step is to decide weathervthe performance of the competing models is statistically different. The nature of an ideal and perfect model is to have both the fractional bias and normalized mean square error equal to 0. The ideal values for geometric mean bias and geometric mean variance is one. Real life models are very rare to be perfect. To determine the reliability of a model the following criteria recommended by Kumar et al. (1993) could be used. The performance of a model can be considered as satisfactory if,

$$NMSE \leq 0.5$$

$$-0.5 \leq FB \leq +0.5$$

New criteria as suggested by Ahuja and Kumar (1996) could be useful to test the reliability of the model. They are:

$$0.75 \leq GMB \leq 1.25$$

The results are good when coefficient of correlation is near to 1.

The performance measures should be calculated using the four different model evaluation procedures in order to obtain a complete picture on the predictions made by the model.

3.5.1 Geometric Mean Bias, GMB

GMB for a single point is determined from Equation as:

$$MG1 = \exp [Ln(Xo1) - Ln(Xp1)]$$

The Geometric Mean of the set of n pairs of Xp and Xo is then:

$$MG\ set = (MG1 \times MG2 \times .... \times MGn)^{(1/n)}$$

3.5.2 Fractional Bias, FB

FB for a single point is determined from Equation as:

$$FB = (Xo - Xp) / [0.5 (Xo + Xp)]$$

Then, for a set of n pair of Xo and Xp, FB is calculated by the simple Average described above. That is:

$$FB = (FB1 + FB2 + ... + FBn) / n$$

3.5.3 Normalized Mean Square Error, NMSE

Normalized mean square error is given by Equation , which is:

$$NMSE = (Xo - Xp)^2 / [(Xo)(Xp)]$$

For a set of n pairs of Xo and Xp, NMSE for the set is calculated by the Average for the set as:

$$NMSE\ set = (NMSE1 + NMSE2 + ... + NMSEn) / n$$

3.5.4 Correlation coefficient:-

$$r = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}}$$

3.6 Objectives of the study

1. To monitor the fine particulate matter concentration at major transport corridors of Delhi.
2. To conduct comparative study of the $PM_{2.5}$ variation at different transport corridors.
3. To develop CALINE 4 model to predict the $PM_{2.5}$ concentration at selected transport corridors.
4. To validate the model and check its applicability for the selected transport corridors in Delhi.

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Chapter 4:- Data Analysis,Result and Discussion

4.1 Monitoring and Modeling Analysis of $PM_{2.5}$ at Madhuban Chowk

The data related to $PM_{2.5}$ concentration was collected by using Haz Dust Sampler (EPAM-5000) at Madhuban Chowk. The concentration variation with time (hourly average value) is presented in Figure 4.1. The concentration at Madhuban Chowk was found low in morning than in afternoon and evening. The maximum and minimum hourly average concentration for the day was found as 680 µg/m^3 and 452 µg/m^3 during 10:00-11:00 and 12:00-13:00 hours respectively.

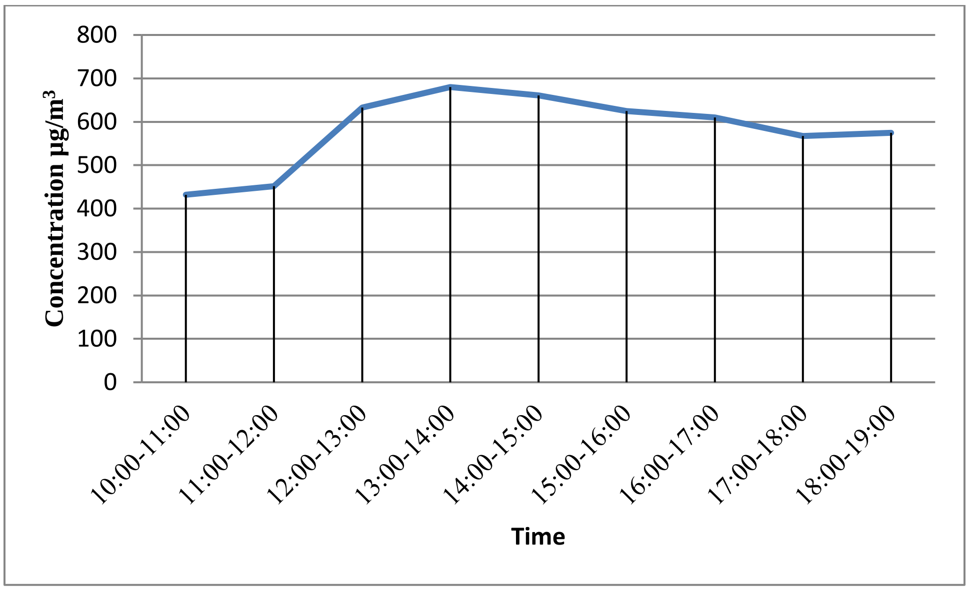

Figure 4.1 Variation of $PM_{2.5}$ throughout the day at Madhuban Chowk

Traffic volume for the same place was also collected on hourly basis with respect to type of vehicle. The total traffic volume and weighted average emission factor for both sides (towards Kohat Enclave and towards Rithala) at Madhuban chowk is presented in Table 4.1 and 4.2 respectively. The maximum traffic volume was observed towards towards Kohat Enclave direction (3342 veh/hr during 10:00 to 11:00 hours) and towards Rithala direction (3483 veh/ hr during 10:00 to 11:00 hours). Since the applied model in the study i.e. CALINE 4 requires emission factor in gm/miles, which is also presented in Table 4.1 and 4.2.

Table 4.1 Traffic Volume and Weighted Emission Factor for traffic at Madhuban Chowk (Towards Kohat Enclave)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total Veh/hr	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	1440	1340	416	74	72	3342	0.1513185
11:00-12:00	1560	1020	302	96	52	3030	0.1558577
12:00-13:00	1540	1080	198	70	18	2906	0.1259532
13:00-14:00	1660	860	294	136	42	2992	0.1670669
14:00-15:00	1580	940	412	148	48	3128	0.1718355
15:00-16:00	1440	760	454	170	60	2884	0.1961888
16:00-17:00	1464	880	388	112	20	2864	0.148535
17:00-18:00	1476	700	288	88	14	2566	0.1417648
18:00-19:00	1530	960	388	80	0	2958	0.1228351

Table 4.2 Traffic Volume and Weighted Emission Factor for traffic at Madhuban Chowk (Towards Rithala)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total Veh/hr	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	1540	1410	354	94	85	3483	0.16030959
11:00-12:00	1650	1116	305	106	64	3241	0.16084462
12:00-13:00	1440	1207	210	55	26	2938	0.12319707
13:00-14:00	1710	970	394	165	96	3335	0.19753061
14:00-15:00	1620	915	423	109	34	3101	0.15203225
15:00-16:00	1520	745	546	210	46	3067	0.19768897
16:00-17:00	1354	975	426	116	25	2896	0.15135069
17:00-18:00	1376	804	264	110	17	2571	0.15023578
18:00-19:00	1836	864	410	70	0	3180	0.12018098

Meteorological data like wind speed, wind direction, atmospheric stability class, mixing height and ambient temperature which is used as input to run CALINE 4, is presented in Table

4.3. The wind direction standard deviation σα follows a law with $\sigma\alpha = 0.32/V$ ms−1 for V≤ 5 m s−1 and $\sigma\alpha = 0.065$ for higher winds (Sylvain M. Joffre and Tuomas Laurila 1988).

Table 4.3 Meteorological data for Madhuban Chowk

Time	Wind speed m/s	Wind direction °	Wind direction std deviation	Atmospheric stability class	Mixing height m	Ambient temperature °C
10:00-11:00	5.22	309.89	23.4	2	325	11.11
11:00-12:00	5.22	309.89	23.4	2	175	11.82
12:00-13:00	5.22	309.89	23.4	2	700	13.33
13:00-14:00	5.22	309.89	23.4	2	700	14.53
14:00-15:00	5.22	309.89	23.4	2	825.5	15.43
15:00-16:00	5.22	309.89	23.4	2	750	15.73
16:00-17:00	5.22	309.89	23.4	2	737.5	15.46
17:00-18:00	5.22	309.89	23.4	2	600	14.66
18:00-19:00	5.22	309.89	23.4	2	400	14.49

Source: Central Pollution Control Board and www.envitras.com

The receptor location which is required by CALINE 4 model is shown in Table 4.4. X and Y are in plane and Z axis is above the plane.

Table 4.4 Receptor location for Madhuban Chowk

Receptor name	X	Y	Z
D1 (m)	10	10	3

The predicted as well as measured concentrations are presented in Table 4.5. The performance evaluation of CALINE 4 result was validated by Geometric Mean Bias, Fractional Bias, Normalized Mean Square Error, and Correlation Coefficient statistics methods. The average value of Normalized Mean Square Error, Fractional Bias method, Geometric Mean Bias method, Correlation coefficient was found as 2.78531E-06, 0.0016439, 0.9980313 and 0.9999984 respectively, which indicates the suitability and applicability of the model in the existing conditions.

Table 4.5 CALINE 4 results and hourly average measured concentration with performance indicators

Time	Measured concentration	Predicted Concentration	NMSE	FB	GMB	Correlation coefficient
10:00-11:00	432	432.7	2.62135E-06	0.0016191	0.9980611	**0.9999984**
11:00-12:00	452	453	4.88386E-06	0.0022099	0.9973544	
12:00-13:00	633	634	2.49176E-06	0.0015785	0.9981095	
13:00-14:00	680	680.8	1.38246E-06	0.0011758	0.9985915	
14:00-15:00	661	662	2.28529E-06	0.0015117	0.9981895	
15:00-16:00	625	626.1	3.09216E-06	0.0017585	0.9978943	
16:00-17:00	610	611.2	3.86233E-06	0.0019653	0.9976469	
17:00-18:00	567	567.9	2.51553E-06	0.001586	0.9981006	
18:00-19:00	575	575.8	1.93304E-06	0.0013903	0.9983347	
Avg	**581.67**	**582.61**	**2.78531E-06**	**0.0016439**	**0.9980313**	

Linear regration analysis is has also been performed between measured and predicted $PM_{2.5}$ concentration to check the validity of the model (Figure 4.2). The value of R^2 is found as 1, which also indicates the best suitability of the model.

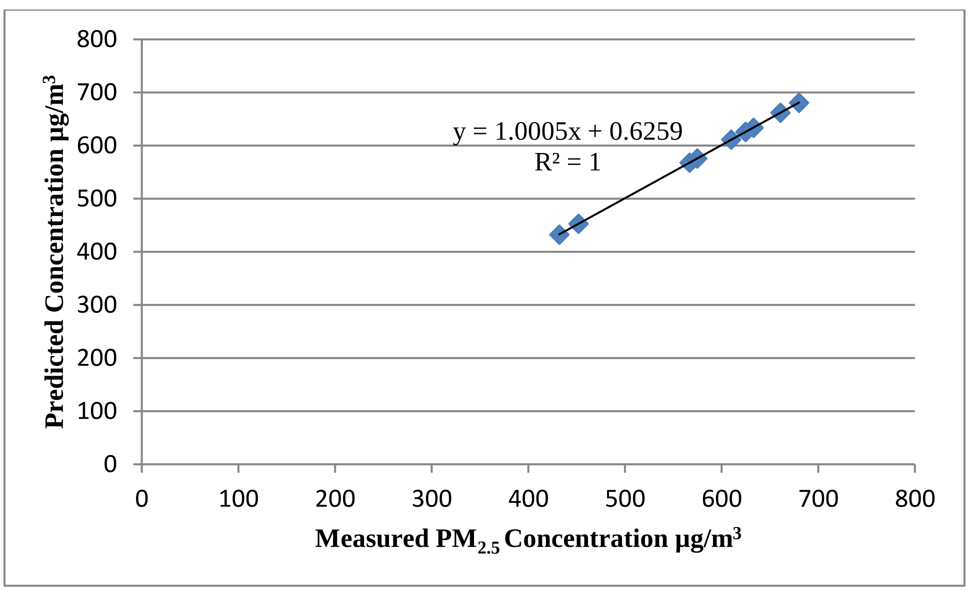

Figure 4.2 Linear regration analysis between measured and predicted concentration of $PM_{2.5}$ at Madhuban Chowk

4.2 Monitoring and Modeling Analysis of $PM_{2.5}$ at Janpat

The average concentration of fine particulate matter with time is depicted in Figure 4.3. The maximum and minimum hourly average concentration was found as 372 μg/m^3 and 150 μg/m^3 during 10:00-11:00 and 16:00-17:00 hours respectively.

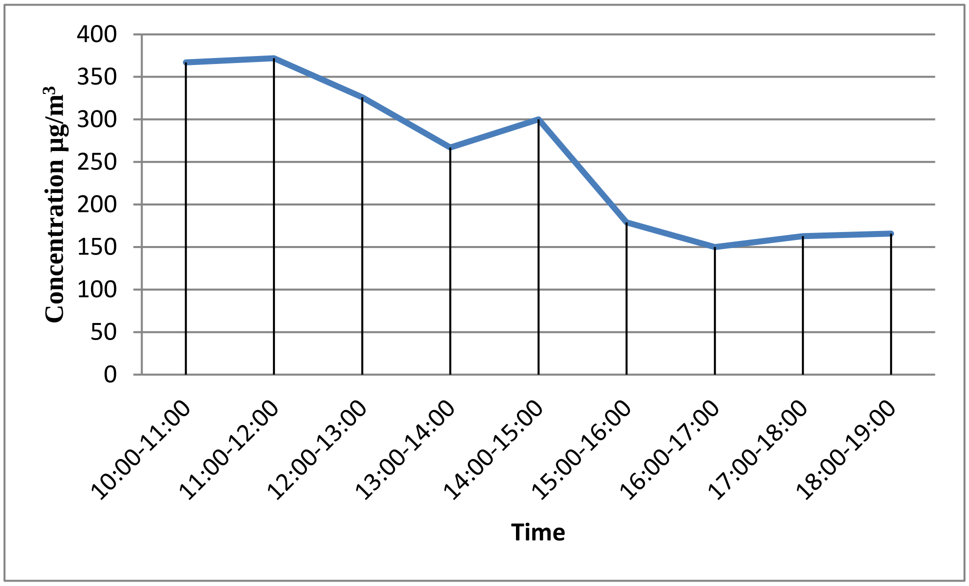

Figure 4.3 Variation of $PM_{2.5}$ throughout the day at Janpat.

The traffic volume along with weighted average emission factor for both the lanes at Janpat are presented in Table 4.6 and Table 4.7. During the traffic monitoring maximum and minimum traffic volume towards Canought Place (CP) was observed 2024 veh/hr and 1368 veh/hr and towards Lodhi Garden it was 1770 veh/hr and 1172 veh/hr.

Table 4.6 Traffic Volume and Emission Factor for traffic at Janpat (Towards CP)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	1222	188	204	32	16	1662	0.1418259
11:00-12:00	1128	408	324	40	4	1904	0.12716952
12:00-13:00	1422	224	224	8	0	1878	0.10905836
13:00-14:00	1372	260	388	4	0	2024	0.10885955
14:00-15:00	916	428	244	12	4	1604	0.1105722
15:00-16:00	816	320	240	12	0	1388	0.10998807
16:00-17:00	648	384	320	8	8	1368	0.11700897
17:00-18:00	736	450	484	8	4	1682	0.11242769
18:00-19:00	732	500	444	12	4	1692	0.11250747

Table 4.7 Traffic Volume and Emission Factor for traffic at Janpat (Towards Lodhi Garden)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	564	244	344	16	4	1172	0.12661676
11:00-12:00	624	156	368	24	4	1176	0.13806621
12:00-13:00	732	184	288	36	0	1240	0.13734871
13:00-14:00	924	312	336	20	0	1592	0.11715178
14:00-15:00	832	270	184	16	4	1306	0.11909754
15:00-16:00	700	252	148	8	8	1116	0.11975193
16:00-17:00	784	248	400	12	4	1448	0.1211435
17:00-18:00	952	332	476	6	4	1770	0.11411629
18:00-19:00	944	240	388	14	4	1590	0.12109622

Meteorological data like wind speed, wind direction, atmospheric stability class, mixing height and ambient temperature data is presented in Table 4.8. The wind direction standard deviation $\sigma\alpha$ follows a law with $\sigma\alpha = 0.32/V$ ms−1 for $V \leq 5$ m s−1 and $\sigma\alpha = 0.065$ for higher winds (Sylvain M. Joffre and Tuomas Laurila 1988).

Table 4.8 Meteorological data for Janpat

Time	Wind speed m/s	Wind direction °	Wind direction std deviation	Atmospheric stability class	Mixing height m	Ambient temperature °C
10:00-11:00	1.59	259.74	23.40	1	175	9.55
11:00-12:00	2.12	276.09	23.40	1	325	10.55
12:00-13:00	1.91	268.64	23.40	1	175	13.1
13:00-14:00	1.57	252.93	23.40	1	700	15.53
14:00-15:00	2.18	275.33	23.40	1	700	18.22
15:00-16:00	2.37	289.25	23.40	1	825.5	19.51
16:00-17:00	2.25	278.32	23.40	1	750	19.7
17:00-18:00	1.75	263.54	23.40	1	737.5	19.3
18:00-19:00	0.68	244.96	23.40	1	600	18.3

Source: Central Pollution Control Board and www.envitras.com

The receptor location is shown in Table 4.9. X and Y are in plane and Z axis is above the plane.

Table 4.9 Receptor location for Janpat

Receptor name	X	Y	Z
D1 (m)	10	10	3

Monitored as well as predicted concentrations are presented in Table 4.10. Different statistical tests like Geometric Mean Bias, Fractional Bias, Normalized Mean Square Error, and Correlation Coefficient statistical methods have been used to validate the applicability of the model. The results of statistical analysis of Normalized Mean Square Error, Fractional Bias method, Geometric Mean Bias method, Correlation coefficient was found as 0.00307, 0.04382, 0.948799 and 0.99789358 respectively, which indicates the suitability and applicability of the model in existing conditions. Linear regration analysis was also performed between measured and predicted $PM_{2.5}$ concentration which is shown in Figure 4.4. The value of R^2 was found as 0.9958 which is near to 1, which indicates the best suitability of the model.

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Table 4.10 CALINE 4 results and hourly average measured concentration with performance indicators

Time	Measured concentration	Predicted Concentration	NMSE	FB	GMB	Correlation coefficient
10:00-11:00	367	379.2	0.00107	0.032699	0.961557	**0.99789358**
11:00-12:00	372	379.4	0.000388	0.019697	0.976665	
12:00-13:00	326	335.3	0.000791	0.028126	0.966844	
13:00-14:00	267	280.1	0.002295	0.047889	0.9442	
14:00-15:00	300	306.1	0.000405	0.020129	0.976159	
15:00-16:00	179	181.6	0.000208	0.01442	0.982862	
16:00-17:00	150	155.4	0.001251	0.035363	0.95849	
17:00-18:00	163	174.3	0.004494	0.067003	0.922795	
18:00-19:00	166	188.9	0.016724	0.12905	0.85649	
Avg	**254.44**	**264.48**	**0.00307**	**0.04382**	**0.948799**	

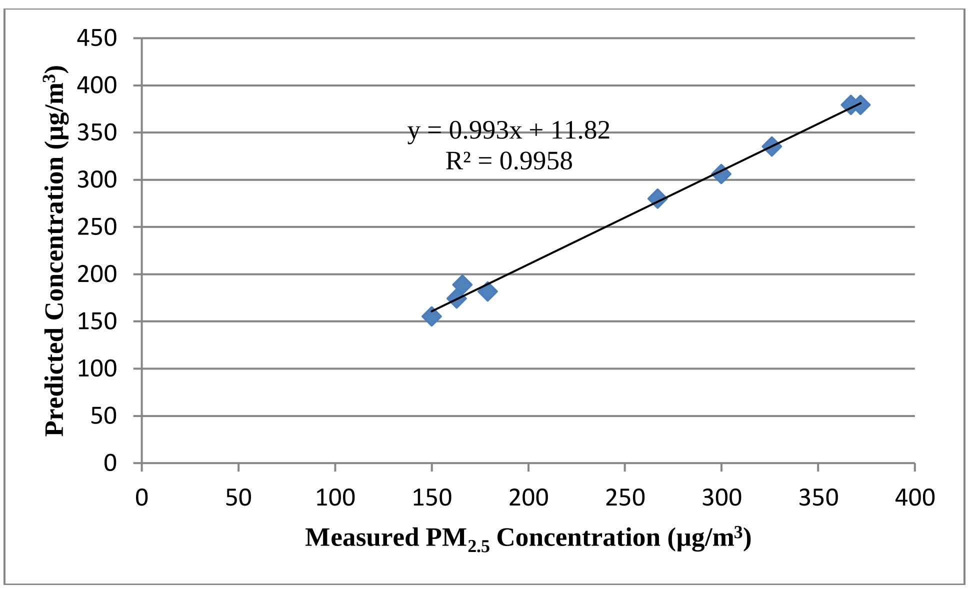

Figure 4.4 Linear regration analysis between measured and predicted concentration of PM $_{2.5}$ at Janpat

4.3 Monitoring and Modeling Analysis of $PM_{2.5}$ at Punjabi Bagh

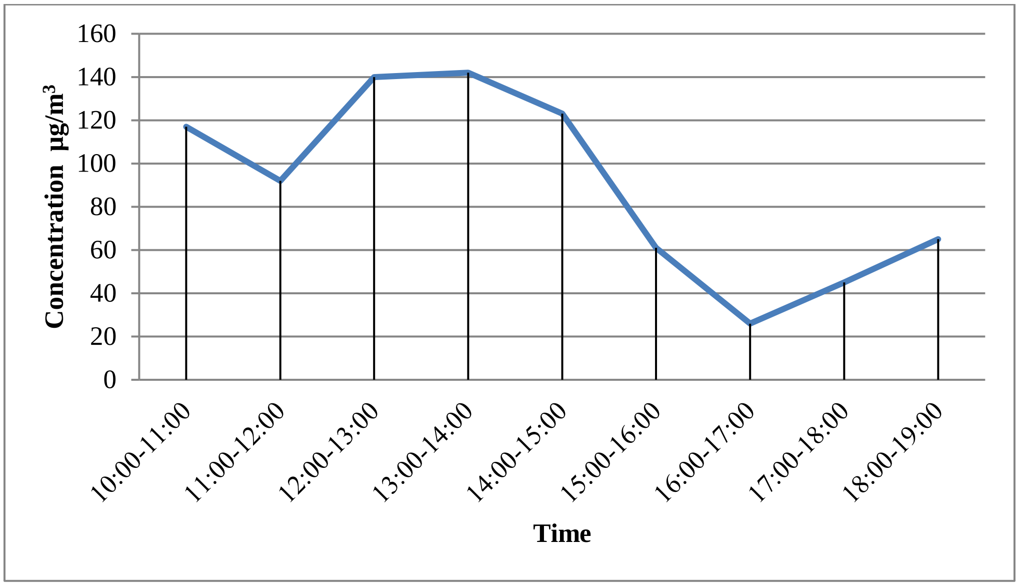

Figure 4.5 Variation of $PM_{2.5}$ throughout the day at Punjabi Bagh

The average concentration variation of fine particulate matter with time is presented in Figure 4.5. The maximum and minimum hourly average concentration for the day was found as 142 µg/m^3 during 13:00 to 14:00 hours and 26 µg/m^3 during 16:00 to 17:00 hours respectively. Traffic volume for the same place was also collected on hourly basis with respect to type of vehicle. The total traffic volume and the weighted average emission factor for both the lanes (towards Shivaji Metro station and towards Punjabi Bagh metro station) at Punjabi Bagh is presented in Table 4.11 and Table 4.12. Monitored maximum traffic volume towards Shivaji Metro and towards Punjabi bagh was observed 4786 veh/hr and 6406 veh/hr during 18:00-19:00 and 10:00-11:00 respectively.

Table 4.11 Traffic Volume and Emission Factor for traffic at Punjabi Bagh (Towards Shivaji Metro Station)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	960	1200	420	42	80	2702	0.157533
11:00-12:00	860	1420	480	72	120	2952	0.184391
12:00-13:00	1020	1200	520	28	108	2876	0.167651
13:00-14:00	1328	1408	912	108	102	3858	0.171775
14:00-15:00	1384	1268	704	48	70	3474	0.144891
15:00-16:00	1368	1248	796	60	32	3504	0.130407
16:00-17:00	2200	1838	448	104	12	4602	0.117822
17:00-18:00	1972	1924	316	104	8	4324	0.11485
18:00-19:00	2312	2072	260	128	14	4786	0.119437

Table 4.12 Traffic Volume and Emission Factor for traffic at Punjabi Bagh (Towards Punjabi Bagh metro station)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	1576	2606	1900	124	200	6406	0.171275
11:00-12:00	1784	1268	1770	116	106	5044	0.166951
12:00-13:00	1520	1112	1672	48	268	4620	0.219421
13:00-14:00	1248	1320	1026	50	104	3748	0.16088
14:00-15:00	1566	1572	1032	80	114	4364	0.161459
15:00-16:00	1532	1600	2384	122	162	5800	0.177951
16:00-17:00	1530	1828	1354	106	54	4872	0.1395
17:00-18:00	1644	1642	1020	128	24	4458	0.135313
18:00-19:00	1464	1528	1198	82	32	4304	0.131352

To run the model different meteorological data such as wind speed, wind direction, atmospheric stability class, atmospheric stability class, mixing height and ambient temperature was used and it is presented in Table 4.13. The wind direction standard deviation $\sigma\alpha$ follows a law with $\sigma\alpha = 0.32/V$ ms^{-1} for $V \leq 5$ m s^{-1} and $\sigma\alpha = 0.065$ for higher winds (Sylvain M. Joffre and Tuomas Laurila 1988). The receptor location which is required by CALINE 4 model is shown in table 4.14. X and Y are in plane and Z axis is above the plane.

Table 4.13 Meteorological data for Punjabi Bagh

Time	Wind speed m/s	Wind direction °	Wind direction std deviation	Atmospheric stability class	Mixing height m	Ambient temperature °C
10:00-11:00	1.68	120.17	68.57	1	325	13.55
11:00-12:00	2.04	129.12	56.47	1	175	14.64
12:00-13:00	2.14	121.56	53.83	1	700	15.94
13:00-14:00	2.11	132.73	54.60	1	700	17.47
14:00-15:00	1.83	132.02	62.95	1	825.5	17.8
15:00-16:00	2.77	105.42	41.59	1	750	17.4
16:00-17:00	3.85	101.74	29.92	1	737.5	16.46
17:00-18:00	3.82	114.74	30.16	1	600	15.39
18:00-19:00	2.8	102.32	41.14	1	400	14.46

Source: Central Pollution Control Board and www.envitras.com

Table 4.14 Receptor location for Punjabi Bagh

Receptor name	X	Y	Z
D1 (m)	10	10	3

The predicted as well as measured fine particulate concentrations are shown in Table 4.15. The performance evaluation of CALINE 4 result was checked by Geometric Mean Bias, Fractional Bias, Normalized Mean Square Error, and Correlation Coefficient statistics methods. The average value of Normalized Mean Square Error, Fractional Bias method, Geometric Mean Bias method, and Correlation coefficient was found as 0.08202, 0.267668, 0.723596 and 0.991006 respectively, which indicates the suitability and applicability of the model in existing condition.

Table 4.15 CALINE 4 results and hourly average measured concentration with performance indicators

Time	Measured concentration	Predicted Concentration	NMSE	FB	GMB	Correlation coefficient
10:00-11:00	117	157.8	0.090163	0.296943	0.698649	**0.991006**
11:00-12:00	92	118.7	0.065281	0.253441	0.736791	
12:00-13:00	140	170.8	0.039672	0.198198	0.787911	
13:00-14:00	142	164	0.020783	0.143791	0.841419	
14:00-15:00	123	147.8	0.033832	0.183161	0.802376	
15:00-16:00	61	87.6	0.132413	0.358008	0.648022	
16:00-17:00	26	41.3	0.218001	0.454681	0.574225	
17:00-18:00	45	58.1	0.065638	0.254122	0.73618	
18:00-19:00	65	85	0.072398	0.266667	0.725004	
Avg	**90.11**	**114.56**	**0.08202**	**0.267668**	**0.723596**	

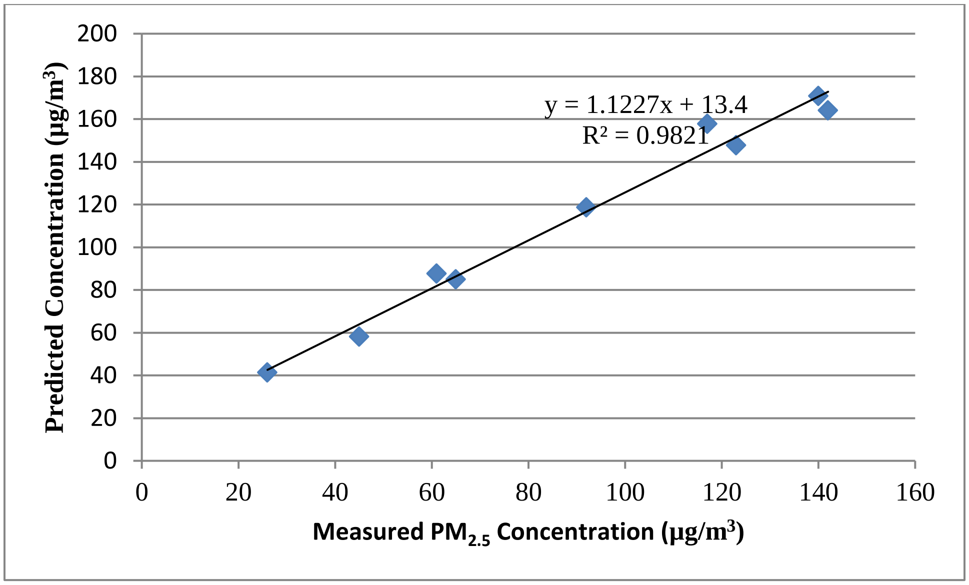

Figure 4.6 Linear regration analysis between measured and predicted concentration of $PM_{2.5}$ at Punjabi Bagh

Linear regration analysis was also performed between measured and predicted $PM_{2.5}$ concentration which is depicted in Figure 4.6. The value of R^2 was found as 0.9821, which indicates the best suitability of the model.

4.4 Monitoring and Modeling Analysis of $PM_{2.5}$ at Karol Bagh

The concentration of fine particulate matter with time at Karol Bagh is presented in Figure 4.7. The concentration at Karol bagh was low in afternoon than other time. The monitored maximum and minimum concentration for the day was found as 111 µg/m3 and 57 µg/m3 during 10:00-11:00 and 17:00 to 18:00 hours respectively.

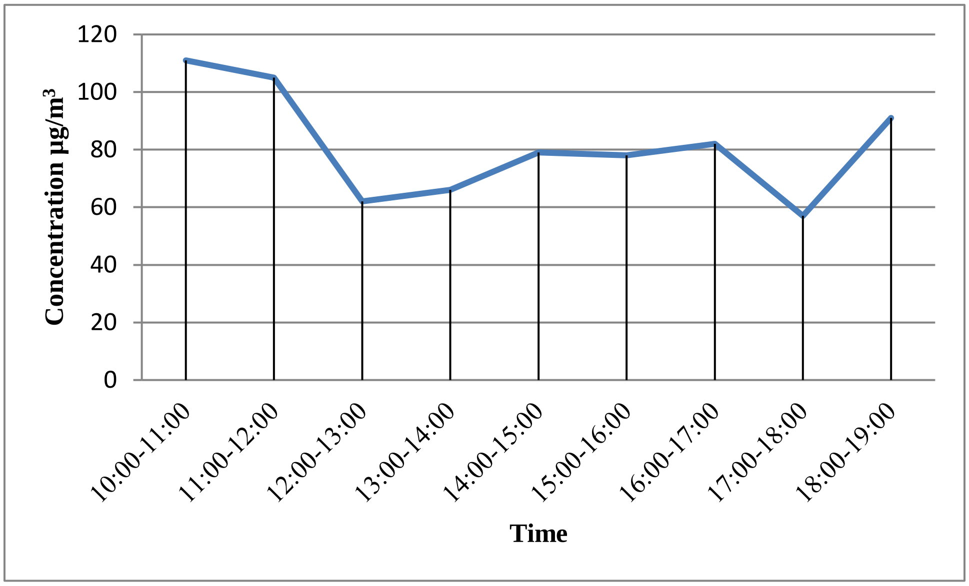

Figure 4.7 Variation of $PM_{2.5}$ throughout the day at Karol Bagh

Traffic volume for the same place was also collected on hourly basis with respect to type of vehicle. The total traffic volume and the weighted average emission factor for both sides (towards Jhandewalan and towards Rajeev Chowk) at Karol Bagh is presented in Table 4.16 and Table 4.17.The monitored maximum traffic volume towards Jhandewalan and towards Rajeev Chowk was observed 3920 veh/hr and 4480 veh/hr during 16:00-17:00 and 10:00-11:00 hours respectively..

Table 4.16 Traffic Volume and Emission Factor for traffic at Karol Bagh (Towards Jhandewalan to karol bagh)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	626	1260	474	142	0	2502	0.14677018
11:00-12:00	760	840	432	125	0	2157	0.15410038
12:00-13:00	860	960	450	111	0	2381	0.14127138
13:00-14:00	1500	1080	500	120	0	3200	0.1339221
14:00-15:00	1168	960	656	97	20	2901	0.1446128
15:00-16:00	934	920	724	168	16	2762	0.1722449
16:00-17:00	1220	1320	1256	124	0	3920	0.13383286
17:00-18:00	1476	1460	824	96	0	3856	0.1208999
18:00-19:00	828	1360	1228	116	0	3532	0.13366178

Table 4.17 Traffic Volume and Emission Factor for traffic at Karol Bagh (Towards Rajiv Chowk)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	1640	2384	380	70	6	4480	0.10130615
11:00-12:00	1524	2488	380	70	6	4468	0.10013083
12:00-13:00	2260	1316	380	70	16	4042	0.11827693
13:00-14:00	1402	1500	406	68	6	3382	0.11240564
14:00-15:00	1184	1862	320	80	8	3454	0.11075231
15:00-16:00	1324	2644	260	80	6	4314	0.09949847
16:00-17:00	1262	2004	320	82	4	3672	0.10721831
17:00-18:00	1068	2480	460	100	7	4115	0.10837774
18:00-19:00	1328	2576	320	60	0	4284	0.09347142

Meteorological data like wind speed, wind direction, atmospheric stability class, mixing height and ambient temperature is used as input to run CALINE 4 model (Table 4.18). The wind direction standard deviation $\sigma\alpha$ follows a law with $\sigma\alpha = 0.32/V\ ms^{-1}$ for $V \leq 5\ m\ s^{-1}$ and $\sigma\alpha = 0.065$ for higher winds (Sylvain M. Joffre and Tuomas Laurila 1988).

Table 4.18 Meteorological data for Karol Bagh

Time	Wind speed m/s	Wind direction °	Wind direction std deviation	Atmospheric stability class	Mixing height m	Ambient temperature °C
10:00-11:00	3	268.94	38.40	1	325	11.22
11:00-12:00	3.38	266.49	34.08	1	175	13.13
12:00-13:00	3.81	277.51	30.24	1	700	14.81
13:00-14:00	4.25	284.38	27.11	1	700	16.35
14:00-15:00	4.63	289.64	24.88	1	825.5	17.48
15:00-16:00	4.83	291.83	23.85	1	750	17.56
16:00-17:00	4.07	286.07	28.30	1	737.5	16.68
17:00-18:00	3.24	302.61	35.56	1	600	15.69
18:00-19:00	2.27	292.79	50.75	1	400	14.45

Source: Central Pollution Control Board and www.envitras.com

The receptor location which is required by CALINE 4 model is shown in table 4.19. X and Y are in plane and Z axis is above the plane.

Table 4.19 Receptor location for Karol Bagh

Receptor name	X	Y	Z
D1 (m)	10	10	3

The predicted as well as measured concentration are presented in Table 4.20. The performance evaluation of CALINE 4 result was tested by Geometric Mean Bias, Fractional Bias, Normalized Mean Square Error, and Correlation Coefficient statics methods. The average 8 hrs measured $PM_{2.5}$ concentration at Karol Bagh was 91.37 µg/m^3 and average predicted concentration was 98.63 µg/m^3. The average value of Normalized Mean Square Error, Fractional Bias method, Geometric Mean Bias method and Correlation coefficient was found as 0.00621, 0.07628, 0.91257 and 0.99661311 respectively, which indicates that the model can be used as an effective tool to predict the concentration in existing condition.

Table 4.20 CALINE 4 results and hourly average measured concentration with performance indicators

Time	Measured Concentration	Predicted Concentration	NMSE	FB	GMB	Correlation coefficient
10:00-11:00	111	120.7	0.00702	0.08373	0.90445	**0.99661311**
11:00-12:00	105	113.9	0.00662	0.08132	0.90708	
12:00-13:00	62	69.2	0.01208	0.10976	0.8766	
13:00-14:00	66	71.6	0.00664	0.0814	0.90699	
14:00-15:00	79	82.7	0.0021	0.04576	0.94661	
15:00-16:00	78	81.6	0.00204	0.04511	0.94735	
16:00-17:00	82	88.2	0.00531	0.07286	0.91634	
17:00-18:00	57	61.4	0.00553	0.07432	0.91472	
18:00-19:00	91	99.8	0.00853	0.09224	0.89525	
Avg	**91.37**	**98.63**	**0.00621**	**0.07628**	**0.91257**	

Linear regration analysis was also done between measured and predicted $PM_{2.5}$ concentration which is shown in Figure 4.8. The value of R^2 was found as 0.9932 which is near to 1, which indicates the suitability of the model.

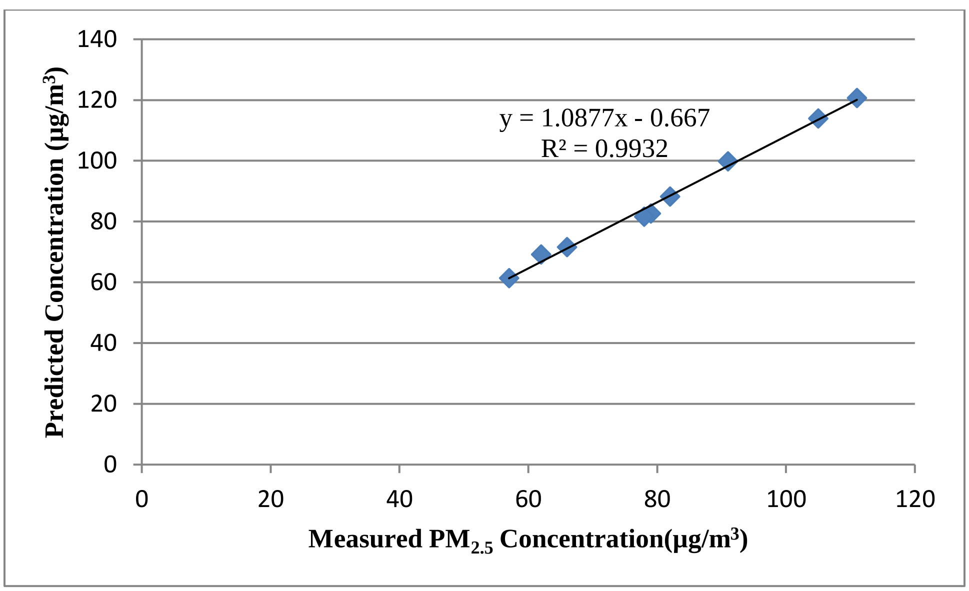

Figure 4.8 Linear regration analysis between measured and predicted concentration of $PM_{2.5}$ at Karol Bagh

4.5 Monitoring and Modeling Analysis of $PM_{2.5}$ at Uttam Nagar

Figure 4.9 depicts the variation of fine particulate matter with time. Fine particulate matter concentration at Uttam Nagar was observed low in afternoon and high in evening. The maximum and minimum concentration for the day was found as 217 µg/m3 and 38 µg/m3 during 18:00-19:00 and 16:00-17:00 hours respectively. The total traffic volume and the weighted average emission factor for both the sides (towards Nazafgarh and towards Uttam Nagar East) at Uttam Nagar are depicted in Table 4.21 and Table 4.22. Monitored maximum and minimum traffic volume towards Nazafgarh was observed 6048 veh/hr and 2718 veh/ hr and towards Uttam Nagar East it was 2542 veh/hr and 1602 veh/hr.

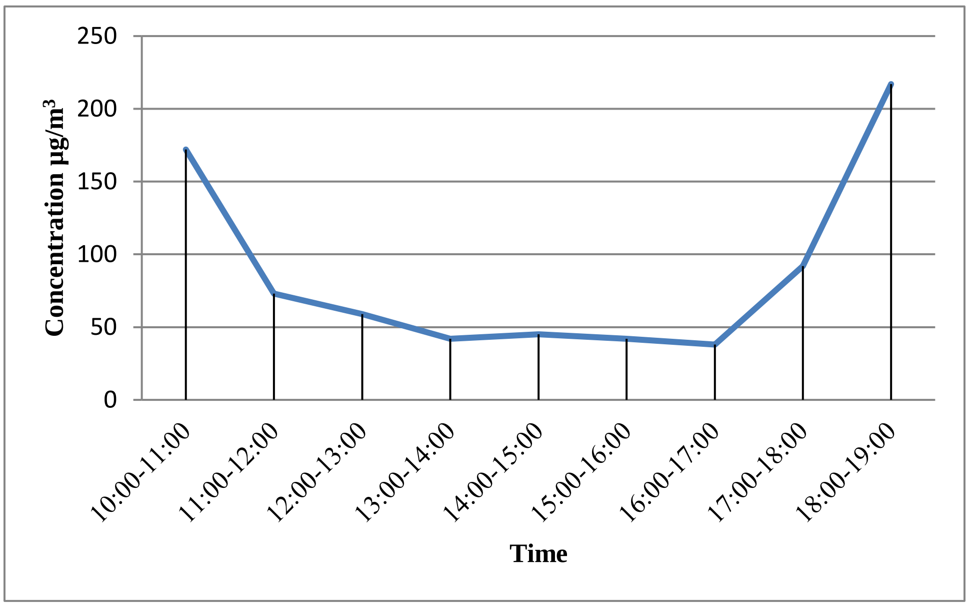

Figure 4.9 Variation of $PM_{2.5}$ throughout the day at Uttam nagar

Table 4.21 Traffic Volume and Emission Factor for traffic at Uttam Nagar (Towards Nazafgarh)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	646	1244	400	356	72	2718	0.27063662
11:00-12:00	618	1520	392	420	36	2986	0.25231585
12:00-13:00	550	1200	232	448	34	2464	0.29773289
13:00-14:00	560	1544	360	412	58	2934	0.26436976
14:00-15:00	840	3000	372	462	60	4734	0.20067188
15:00-16:00	600	3500	400	480	36	5016	0.18595271
16:00-17:00	618	4300	600	500	30	6048	0.16864467
17:00-18:00	512	2581	712	612	44	4461	0.24245201
18:00-19:00	696	3140	368	416	24	4644	0.1771736

Table 4.22 Traffic Volume and Emission Factor for traffic at Uttam Nagar (Towards Uttam Nagar East)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	514	1040	200	186	72	2012	0.2422819
11:00-12:00	492	760	92	160	100	1604	0.29684645
12:00-13:00	501	880	200	180	80	1841	0.26346565
13:00-14:00	750	988	344	428	32	2542	0.28809755
14:00-15:00	560	978	468	184	32	2222	0.20282724
15:00-16:00	360	684	252	270	36	1602	0.30441296
16:00-17:00	520	1080	476	484	72	2632	0.33051872
17:00-18:00	440	932	480	216	16	2084	0.21302462
18:00-19:00	640	1168	420	228	12	2468	0.19296633

Meteorological data like the wind speed, wind direction, atmospheric stability class, mixing height and ambient temperature used as input to run CALINE 4 is presented in Table 4.23. The wind direction standard deviation $\sigma\alpha$ follows a law with $\sigma\alpha = 0.32/V$ ms−1 for $V \leq 5$ m s−1 and σα = 0.065 for higher winds (Sylvain M. Joffre and Tuomas Laurila 1988). The receptor location which is required by CALINE 4 model is shown in table 4.24. X and Y are in plane and Z axis is above the plane.

Table 4.23 Meteorological data for Uttam Nagar

Time	Wind speed m/s	Wind direction °	Wind direction std deviation	Atmospheric stability class	Mixing height m	Ambient temperature °C
10:00-11:00	2.13	267.38	54.08	1	325	13.63
11:00-12:00	3.46	294.34	33.29	1	175	15.83
12:00-13:00	4.49	292.21	25.66	1	700	17.18
13:00-14:00	4.96	313.16	23.23	1	700	17.65
14:00-15:00	4.19	313.7	27.49	1	825.5	18
15:00-16:00	4.08	306.5	28.24	1	750	17.98
16:00-17:00	4.21	303.98	27.36	1	737.5	17.49
17:00-18:00	3.61	308.78	31.91	1	600	16.01
18:00-19:00	2.52	300.6	45.71	1	400	14.89

Source: Central Pollution Control Board and www.envitras.com

Table 4.24 Receptor location for Uttam Nagar

Receptor name	X	Y	Z
D1 (m)	10	10	3

Table 4.25 CALINE 4 results and hourly average measured concentration with performance indicators

Time	Measured concentration	Predicted Concentration	NMSE	FB	GMB	Correlation coefficient
10:00-11:00	172	189.2	0.009091	0.095238	0.892033	**0.999000897**
11:00-12:00	73	80.1	0.008621	0.09275	0.894704	
12:00-13:00	59	64.5	0.007949	0.089069	0.898669	
13:00-14:00	42	43.3	0.000929	0.030481	0.964119	
14:00-15:00	45	46.8	0.001538	0.039216	0.954073	
15:00-16:00	42	45.2	0.005394	0.073394	0.915742	
16:00-17:00	38	42.7	0.013614	0.116481	0.869543	
17:00-18:00	92	96.1	0.001901	0.043594	0.949077	
18:00-19:00	217	226.6	0.001874	0.043282	0.949431	
Avg	**86.67**	**92.72**	**0.005657**	**0.069278**	**0.920262**	

The predicted as well as measured concentrations are shown in Table 4.25. The performance evaluation of CALINE 4 result was checked by Geometric Mean Bias, Fractional Bias, Normalized Mean Square Error, and Correlation Coefficient statics methods. The average 8 hrs measured $PM_{2.5}$ concentration at Uttam Nagar was 86.67µg/m^3 and average predicted concentration was 92.72 µg/m^3. The average value of Normalized Mean Square Error, Fractional Bias method, Geometric Mean Bias method and Correlation coefficient was found as 0.005657, 0.069278, 0.920262 and 0.999000897 respectively, which indicates the better performance of the model.

Linear regration analysis was also done between measured and predicted $PM_{2.5}$ concentration which is shown in Figure 4.10. The value of R^2 was found as 0.998, which also indicates the best suitability of the model.

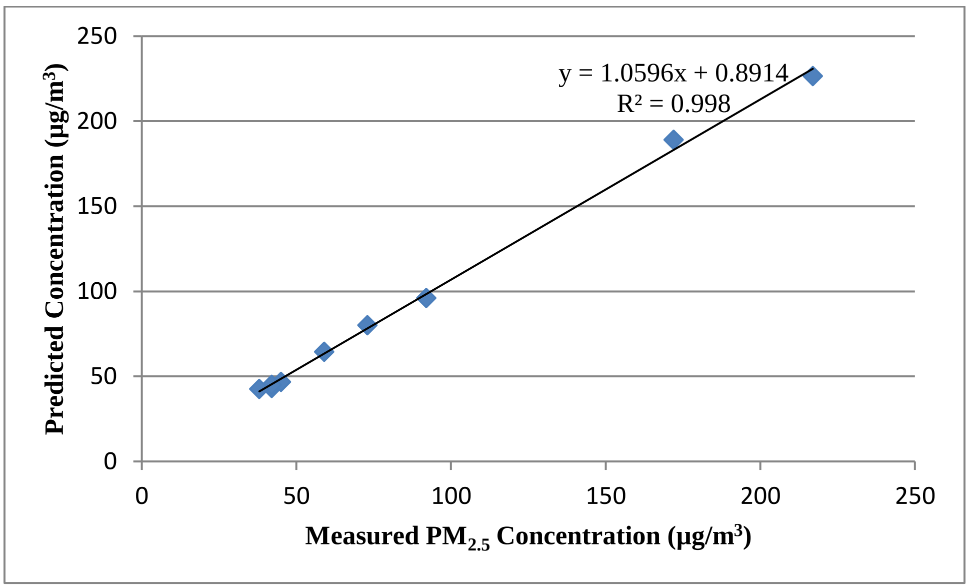

Figure 4.10 Linear regration analysis between measured and predicted concentration of $PM_{2.5}$ at Uttam Nagar

4.6 Monitoring and Modeling Analysis of $PM_{2.5}$ at Laxmi Nagar

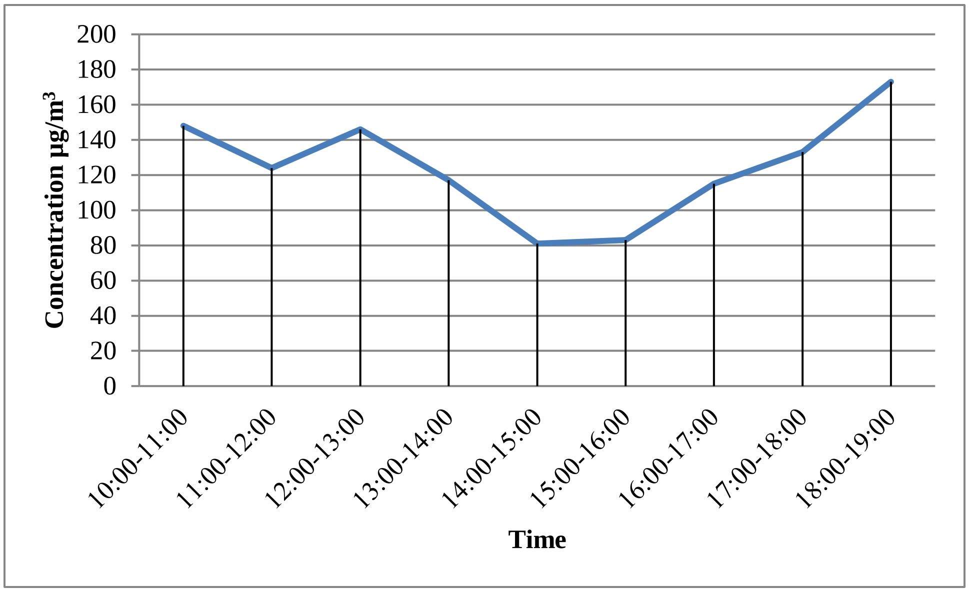

Figure 4.11 Variation of $PM_{2.5}$ throughout the day at Laxmi Nagar.

The average concentration of fine particulate matter with time at Laxmi Nagar is presented in Figure 4.11. $PM_{2.5}$ Concentration at Laxmi Nagar was low in afternoon and high in evening. The monitored maximum and minimum concentration for the day was found as 173 µg/m3 and 81 µg/m3 during 18:00-19:00 and 14:00-15:00 hours respectively. Traffic volume for the same place was also collected on hourly basis with respect to type of vehicle. The total traffic volume and the weighted average emission factor for both the sides (towards ITO and opposite side) at Laxmi Nagar is presented in Table 4.26 and Table 4.27 respectively. Maximum and minimum traffic volume towards ITO was observed 5124 veh/hr and 4038 veh/ hr and opposite site it was 7246 veh/hr and 3874 veh/hr.

Table 4.26 Traffic Volume and Emission Factor for traffic at Laxmi Nagar (Towards ITO)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	1266	1998	1416	370	28	5078	0.181814
11:00-12:00	1522	1374	1186	360	14	4456	0.189669
12:00-13:00	1600	1966	800	300		4666	0.158032
13:00-14:00	1700	1674	850	320		4544	0.167585
14:00-15:00	1684	1454	1260	430	32	4860	0.203847
15:00-16:00	1756	1318	800	380		4254	0.19012
16:00-17:00	2000	1066	778	190	4	4038	0.150532
17:00-18:00	2108	1036	970	192		4306	0.1486
18:00-19:00	2188	1232	1350	354		5124	0.175358

Table 4.27 Traffic Volume and Emission Factor for traffic at Laxmi Nagar (opposite side)

Time	Cars/ Jeep/ Van	Two wheeler	Three wheeler	Mini bus /Bus	Mini Truck/ Truck	Total	Weighted Avg Emission Factor (gm/miles)
10:00-11:00	1840	1660	494	182		4176	0.135849
11:00-12:00	1630	2280	924	292	8	5134	0.152243
12:00-13:00	1760	1800	530	124	10	4224	0.124084
13:00-14:00	1100	1850	796	120	8	3874	0.125565
14:00-15:00	1720	2372	822	238	8	5160	0.13957
15:00-16:00	1400	2200	730	224	8	4562	0.141907
16:00-17:00	1160	2636	570	156		4522	0.117468
17:00-18:00	1100	3588	542	182	2	5414	0.112277
18:00-19:00	1350	5012	630	230	24	7246	0.113551

The different meteorological data used as input to run the model, is presented in Table 4.28. The wind direction standard deviation $\sigma\alpha$ follows a law with $\sigma\alpha = 0.32/V$ ms^{-1} for $V \leq 5$ $m s^{-1}$ and $\sigma\alpha = 0.065$ for higher winds (Sylvain M. Joffre and Tuomas Laurila 1988).

Table 4.28 Meteorological data for Laxmi Nagar

Time	Wind speed m/s	Wind direction °	Wind direction std deviation	Atmospheric stability class	Mixing height m	Ambient temperature °C
10:00-11:00	3.03	267.24	38.02	1	325	14.6
11:00-12:00	5.01	289.44	22.99	2	175	16.88
12:00-13:00	5.24	289.44	21.98	2	700	18.43
13:00-14:00	5.64	294.08	20.43	2	700	19.18
14:00-15:00	6.01	308.65	19.17	2	825.5	19.56
15:00-16:00	5.83	305.26	19.76	2	750	19.37
16:00-17:00	5.36	305.59	21.49	2	737.5	18.61
17:00-18:00	4.14	291.5	27.83	1	600	17.29
18:00-19:00	2.8	276.22	41.14	1	400	15.93

Source: Central Pollution Control Board and www.envitras.com

The receptor location which is required by CALINE 4 model is shown in table 4.29. X and Y are in plane and Z axis is above the plane. The predicted as well as measured concentrations are presented in Table 4.30. The performance evaluation of CALINE 4 result was checked by Geometric Mean Bias, Fractional Bias, Normalized Mean Square Error, and Correlation Coefficient statics methods. The average 8 hrs measured $PM_{2.5}$ concentration at Uttam Nagar was 124.44 $\mu g/m^3$ and average predicted concentration was 131.37 $\mu g/m^3$. The average value of Normalized Mean Square Error, Fractional Bias method, Geometric Mean Bias method, Correlation coefficient was found as 0.003488, 0.046981, 0.945208 and 0.994137 respectively, which indicated suitability and applicability of the model in existing condition.

Table 4.29 Receptor location for Laxmi Nagar

Receptor name	X	Y	Z
D1 (m)	10	10	3

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Table 4.30 CALINE 4 results and hourly average measured concentration with performance indicators

Time	Measured concentration	Predicted Concentration	NMSE	FB	GMB	Correlation coefficient
11:00	148	165.7	0.012775	0.112847	0.873352	**0.994137**
12:00	124	130.8	0.002851	0.053375	0.938007	
13:00	146	151	0.001134	0.03367	0.960439	
14:00	117	120.4	0.000821	0.028644	0.966244	
15:00	81	82.2	0.000216	0.014706	0.982526	
16:00	83	84.4	0.00028	0.016726	0.980149	
17:00	115	116.3	0.000126	0.011241	0.986615	
18:00	133	139.4	0.002209	0.04699	0.945219	
19:00	173	192.1	0.010977	0.104629	0.882023	
Avg	**124.44**	**131.37**	**0.003488**	**0.046981**	**0.945208**	

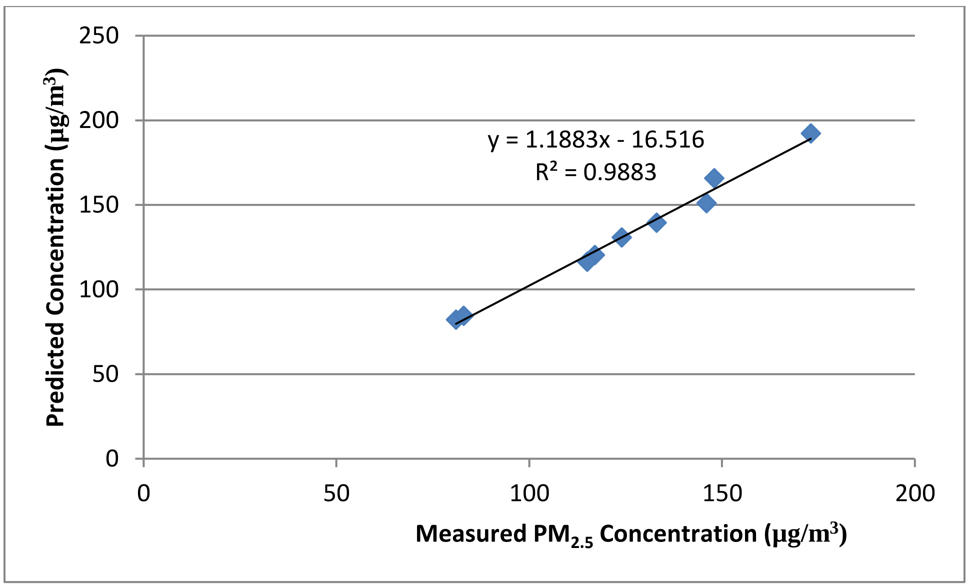

Figure 4.12 Linear regration analysis analysis between measured and predicted concentration of $PM_{2.5}$ at Laxmi Nagar

Linear regration analysis was also perfomed between measured $PM_{2.5}$ concentration and predicted $PM_{2.5}$ concentration which is shown in Figure 4.12. The value of R^2 is found as 0.9983, which also indicates the best suitability of the model.

Chapter 5:- Conclusion

In the present study, monitoring and modeling of fine particulate matter is carried out at six transport corridors of Delhi i.e. Madhuban Chowk, Janpat, Punjabi Bagh, Karol Bagh, Uttam Nagar and Laxmi Nagar. The concentration of fine particulate matter ($PM_{2.5}$) was found to be relatively high in morning period at Janpat and Karol Bagh. The reason behind high concentration of $PM_{2.5}$ during morning may be the movement of commuters towards their workplace, as the traffic volume increases during this particular period. Where as Uttam Nagar and Laxmi Nagar transport corridors showed relatively high concentration of fine particulate matter during evening time. It may be due to the travel of people towards their home place after leaving the office, in evening. During the monitoring of $PM_{2.5}$ concentration at different transport corridors, two corridors namely Maduban Chowk and Punjabi Bagh showed the higher concentration of fine particulate matter during afternoon time.

During the study among all the selected transport corridors maximum 8 hrs average concentration was found at Madhuban Chowk and minimum is at Uttam Nagar. Maduban Chowk and Janpat showed relatively higher concentration than others in chosen cluster. It may be due to construction activities. The difference between minimum and maximum hourly average concentration of $PM_{2.5}$ was 57.4% for Madhuban Chowk, 148% for Janpat, 446% for Punjabi Bagh, 94.73% for Karol Bagh, 471% for Uttam Nagar, 113.58% for Laxmi Nagar with reference to minimum concentration value.

During the study CALINE 4 model has been used to predict the $PM_{2.5}$ concentration and it is compared with the monitored concentration at the selected transport corridors. The values of NMSE, FB, GMB, correlation coefficient and R^2 value (coefficient of determination) were found well within the prescribed limits. The value of coefficient of correlation found as 0.9999 at Madhuban Chowk, 0.9978 at Janpat, 0.9910 at Punjabi Bagh, 0.9966 at Karol Bagh, 0.9990 at Uttam Nagar 0.9941 at Laxmi Nagar all of which are near to 1, which indicates the suitability and applicability of the model in city like Delhi. On the basis of the study it is concluded that the CALINE 4 model may be used as an effective tool to predict the pollutant concentrations near roadways.