Seasonal Patterns of $PM_{2.5}$ Concentration in Delhi Technological University Campus

A DISSERTATION

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IN

ENVIRONMENTAL ENGINEERING

Submitted by:

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(2K16/ENE/14)

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CANDIDATE'S DECLARATION

I **PRAVA GUPTA**, Roll No. **2K16ENE14** of M.TECH ENVIRONMENTAL ENGINEERING, hereby declare that the project Dissertation titled "**Seasonal patterns of $PM_{2.5}$ concentration in Delhi Technological University Campus** "which is submitted by me to the Department of **Environmental Engineering,** Delhi technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowsship or other similar title or recognition.

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CERTIFICATE

I hereby declare that the Project Dissertation title "**Seasonal patterns of $PM_{2.5}$ concentration in Delhi Technological University Campus"** which is submitted by PRAVA GUPTA, Roll No. 2K16ENE14 Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under our supervision.

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ABSTRACT

The average concentration of pollutant $PM_{2.5}$ during monsoon (August to September 2017), post monsoon (October to November 2017), winter (December 2017 to January 2018) and summer (April to May 2018) was observed at DTU Delhi for four hour (12pm to 4 pm).

The seasonal analysis reveals that the concern pollutant i.e. $PM_{2.5}$ concentration is higher in winter and lowest in monsoon and moderate in summer. The concentration of $PM_{2.5}$ is higher in winter due to the limited pollutant dispersion and lower concentration during monsoon due to rainy season because in monsoon pollutants are wash out from atmosphere and deposited on the ground surface.

The maximum concentration of $PM_{2.5}$ found during the study is 528.50μg/m^3 in winter and 29.35μg/m^3in monsoon. The study reveals the comparative analysis of concentration of $PM_{2.5}$ during past three years of Diwali. It was found that the average concentration of $PM_{2.5}$ during Diwali days are 430 μg/m^3 ,1237 μg/m^3 and 657 μg/m^3 in 2015, 2016 and 2017 respectively which is more than 8 to 20 times of standard values prescribed by NAAQS.

Keywords: Particulate matters, visibility, washout pattern, summer, monsoon, post monsoon, winter, fire crackers, mixing height, Air quality.

CONTENTS

Chapter 1

INTRODUCTION

1.1Background

Delhi, the capital of India (latitude 28°4' N and longitude 77°2' E), is located in central India, covering 1483 km^2. It is the third most populated city in India with a population of more than 16 million. Naturally, this has caused environmental stress and atmospheric concentration levels of criteria pollutants particulate matter, sulphur dioxide and nitrogen oxides continue to pose serious public health risks for sensitive population in Delhi [1]. The pollution levels in Delhi have been rising due to continuous increase in number of motor vehicles [2], counteracting the benefits of control programmes that were implemented. Other sources of pollutants include coal-based thermal power plants, small-scale industries and non-road sources such as construction activities. Meteorological variables, particularly the prevailing winds blowing from northwest in winter and from southwest in summer [3] play a significant role in inducting industrial pollutants and pollutants from roadways into residential areas [4] causing widespread air pollution. Several emission reduction measures such as the use of heavy-duty Compressed Natural Gas engines (CNG) replacing diesel-fuelled engines, strict vehicular inspection and maintenance procedures, establishment of alternative mode of transport such as the metro and stricter controls on industrial pollution have been implemented to improve local air quality. Scientists have evaluated the effective- ness of these controls on air pollution and discovered a decrease in air pollutants due to a switch from diesel to CNG in Delhi's transport system [5]. However, an increase in NO_x concentrations after the switch was observed [6,7]. Further, there was no discernible impact on ambient PM10 and CO concentrations noted, stemming from CNG implementation [8]. SO_2 and NO_x (NO + NO_2) are important primary precursors emitted by fossil fuel combustion from industrial point sources and coal-fired thermal power plants. Heavy-duty vehicles burning diesel fuel are important sources of NO_2 as well. NO2and SO2 are important contributors towards secondary nitrate and sulphate formation through a series of complex reactions, which are major components of fine particulate matter ($PM_{2.5}$). Sources of fine particles include all types of combustion

including motor vehicles, power plants, residential wood burning, forest fires, agriculture burning and some industrial processes. The study and subsequent control of secondary pollutants are further complicated by the nonlinear nature of their formation processes and the impact of meteorological variability on their concentrations [9, 10].

Atmospheric particulate matter (PM) can be classified as PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ by size with mass median aerodynamic diameter less than 10 μm , 2.5μm and 1μm respectively. PM plays pivotal role in the climate change, cloud dynamics, health impact, fog formation and visibility through a variety of atmospheric processes (Pillai *et al*., 2002; Pope *et al*.,2002; Das *et al*., 2009). High concentrations in the PM_{10} ,$PM_{2.5}$ and $PM_{1.0}$ can cause human health problems, related to both short-term and long-term exposure to these particles (Schwartz *et al*., 1996; Massey *et al*., 2009; Chate, 2010).

During a dust storm, Choi and Choi, (2008) reported high concentrations in the variation

of PM_{10} ,$PM_{2.5}$ and $PM_{1.0}$ owing to circulation patterns and boundary layer heights in the Korean mountainous coast.Li *et al*. (2009) have presented PM2.5 particles at an urban, industrial and coastal site in Tianjin, China. Also, recently Sabbagh-Kupelwieser *et al*. (2010) have presented PM_{10} ,$PM_{2.5}$ and $PM_{1.0}$ at Vienna, Austria.

In Delhi, India, measurements of aerosol number size distributions have already been performed for air-quality monitoring and aerosol formation purposes. For instance, high concentrations of ultrafine particles (diameter < 0.1 μm) were frequently recorded in the urban atmosphere of Delhi (Monkkonen *et al*, 2004). With the rapid urbanization and Corresponding increase in the traffic and energy consumption, there has been growing evidence that ambient concentration levels of $PM_{2.5}$ and $PM_{1.0}$ are also high in Delhi (Gupta *et al* 2007). The major source of PM_{10} ,$PM_{2.5}$ and $PM_{1.0}$ are referred as windblown dust, secondary aerosol, coal combustion, traffic exhausts and biomass burning, etc. (Tiwari *et al*. 2009). Furthermore, $PM_{2.5}$ and $PM_{1.0}$ remain air-borne through nonlinear processes for days-to-weeks during monsoon months as washout processes are least efficient for cleansing particles in these size bins. Since background number concentrations of PM_{10} ,$PM_{2.5}$ and $PM_{1.0}$ particles are very high in megacities (e.g. Delhi) their

formation and removal processes by rainfall are not clearly understood. Aerosol distributions presented by taking seasonal or

annual simple averages of data can suppress the peaks owing to local effects and also by variations with rain scavenging over very short durations (Chate *et al*., 2005). Therefore, time series distributions of PM_{10} ,$PM_{2.5}$ and PM_1 can be presented by performing running mean on raw data in order to address environmental and rain scavenging processes in those size regimes. The National Ambient Air Quality Standards (http://cpcb.nic.in/National Ambient Air Quality Standards.php) for PM_{10} and $PM_{2.5}$ are set at averages over 24 hours (1440 minutes). The main advantage in time series presentation of PM_{10} ,$PM_{2.5}$ and PM_1 mass concentrations is that a mean can be performed around Every point along a continuous raw data. Furthermore, data points with very high peaks for random spikes due to electronic glitches are to be removed from the raw data. Assessment of PM_{10} ,$PM_{2.5}$ and PM_1 concentrations over daily, monthly, seasonal and data points ensembles mean cycles, assumes significance in environmental, health and climatic perspective. Results of such assessments in terms of running means on analysing data of airborne PM_{10} ,$PM_{2.5}$ and PM_1 from August 2007 to October, 2008, at Delhi are presented here. In order to interpret effective variability of PM_{10} ,$PM_{2.5}$ and PM_1 levels, the relative humidity, temperature and particle concentrations are analyzed over daily, seasonal and data points ensemble running mean and also by simply averaging the entire data of aerosols over these ensembles. The PM_{10} ,$PM_{2.5}$ and PM_1 components in different seasons in Delhi are interpreted in terms of physical processes, which in general control the ambient PM concentrations.

Atmospheric aerosols consist of particles of both natural and anthropogenic origin. It is now well established that the elements from natural sources are generally found in coarse particles whereas elements emitted from anthropogenic activities are associated with fine particles (Seinfeld,1986). Early studies were aimed at assessment of the general pollution levels in urban areas like estimation of the amount of the TSPM, and determination of metal concentrations in it. Later, the realisation came that it is not only the concentrations of TSPM and metals but the size distribution of particles and associated metal concentrations, which are important from the viewpoint of identification of the pollution sources and their adverse impact on human health (Lave and Seskin,1970; McCormac,1971; Epstein,1975;Phalen et al., 1986).

In the past, several investigations have been made on the measurements of size distribution of aerosols and associated elemental concentrations in urban areas (Zoller et al.,1974; Spengler and Thurston, 1983;Orsini et al.,1986; Anderson et al., 1988; Infante and Acosta, 1991). Of late Key wood et al. (1999) determined the relationships between size segregated mass concentration and ultra fine particles in urban areas of Australia. A study on the size

distribution of metals in urban aerosols in Seville (Spain) was done by Espinosa et al. (2001). They concluded that potentially toxic metals, such as nickel, lead and cadmium are mainly accumulated in smaller particles. The accumulation of Pb and Cd in small particles was also seen in the work of Allen et al. (2001) who studied the size distribution of atmospheric aerosols in the UK. Eleftheriadis and Colbeck (2001) determined the spatial distributions of earth and trace metals in coarse atmospheric aerosols. Some more important studies on, size distribution of particulate matters and associated metals and their source apportionment, in various parts of world have been carried out in recent past (Cabada et al., 2004; Kawanaka et al., 2004; Salma et al., 2005; Samara and Voutsa, 2005; Wanget al., 2006). However in the context of urban environment in India,the studies on size distribution of TSPM and associated metal concentration are rather limited. A few of them are as follows: a study on the size distribution and chemical composition of atmospheric aerosols over Deccan plateau in India was carried out by Khemani et al. (1982). Later Mishra (1988) determined the size distribution of atmospheric aerosols and its chemical composition. Sharma and Patil (1992) studied the size distribution of atmospheric aerosols and identified their sources in Mumbai using factor analysis. Sharma and Patil (1994) later used a chemical mass balance model for source apportionment of aerosols in Mumbai. Particle size distribution of atmospheric aerosols at traffic junctions in Mumbai have also beenstudied by Kumar et al. (2001). Parmar et al. (2001) conducted a study on the size distribution of atmospheric aerosols at Agra, a city famous for its architectural marvel Taj Mahal. Recently some more important studies were carried out by Monkkonen et al. (2004), Yadav and Rajamani(2006) and Srivastava and Jain (2006).

All the above-mentioned studies suggest the importance of understanding the particle size distribution and associated metal concentration of TSPM, and the possible correlations between different size fractions. Theseconsiderations have prompted the present study with the objective to determine the size distribution of

TSPM and metal concentrations associated with each size fraction, their possible sources as well as the correlations between different size fractions in the urban environment of Delhi, a city supposed to be one of the most polluted cities in the world.

It lies in the subtropical belt. Its climate is semiarid, consists of summer (March–June), monsoon (July–October) and winter (November–February) seasons.

1.2 Physical Characteristics and Sources.

Particulate matter is the term given to the tiny particles of solid or semi-solid material found in the atmosphere. Particulates in the atmosphere range in size across many orders of magnitude. The expression "particulate size" is based on particle behaviour in the earth's gravitational field. The aerodynamic equivalent diameter refers to a spherical particle of unit density (1 g /cm^3) that falls at standard velocity. Size, because it determines atmospheric lifetime and lung deposition, is a very important characteristic of particulates. Particulates ranging in size from <0.1 to 50 μ are called Total Suspended Particulates (TSP). Particulates larger than 50 μ tend to settle out of the air whereas particulate matter 10 μ in diameter and smaller are considered inhalable. This particulate matter is commonly referred to as PM_{10}. The terms "fine" and "coarse" were originally intended to apply to the two major atmospheric particle distributions that overlap in the size range between 1 and 3 μ diameters. Currently, fine is referred to as $PM_{2.5}$ (particulates with a diameter <2.5 μ) and coarse as PM_{10} (particulates with a diameter <10 μ). By far, the majority of man-made particulates are in the 0.1 to 10 μ diameter range. Particulates larger than 10 μ are usually due to sand and dirt blown by winds from a variety of sites and usually contain large amounts of silica.

The chemical complexity of airborne particles requires that the composition and sources of a large number of primary and secondary components be considered. Primary particulates are emitted directly into the atmosphere from a variety of sources. Secondary particulates are formed in the atmosphere as a result of chemical processes. Major components of $PM_{2.5}$ particles are sulphate, strong acids, ammonium, nitrate, organic compounds, trace metals, elemental carbon, and water. Sulphur dioxide, nitrogen oxides, and certain organic compounds are major precursors of fine secondary particulate matter.

Nitric oxide reacts with ozone to form nitrogen dioxide. Sulphur dioxide and nitrogen dioxide react with the hydroxyl radical to form sulphuric and nitric acid, respectively. Nitrogen dioxide also reacts with ozone to form nitric acid through a sequence of reactions involving the nitrate radical. These acids may react with ammonia to form ammonium sulphates and nitrates. Some types of higher molecular weight organic compounds react with hydroxyl radicals to form oxygenated organic compounds that can condense onto existing particles.

Sulphur dioxide dissolved in clouds and fog droplets may react with ozone, hydrogen, and oxygen to form sulphuric acid or sulphates that lead to particulates when the water evaporates.

The formation of secondary particulate matter depends on reactions between species which are normally present in the atmosphere but that occur in higher concentrations during smog. Since smog formation increases with temperature and sunlight, secondary particulate matter Peaks during the summer months in most areas of the Delhi.

from the oxidation of sulphur compounds emitted from the oceans and wetlands, oxidation of nitrogen oxides from natural forest fires and lightning, and the oxidation of hydrocarbons such as terpenes emitted by vegetation. Natural sources of fine particulate matter include wind-blown dust, sea salt, particulates formed from the oxidation of sulphur compounds emitted from the oceans and wetlands, oxidation of nitrogen oxides from natural forest fires and lightning, and the oxidation of hydrocarbons such as terpenes emitted by vegetation. PM_{10} particulates (coarse) are generally emitted from sources, such as vehicles, materials handling, and crushing and grinding operations, as well as windblown dust as shown in Fig.1.1

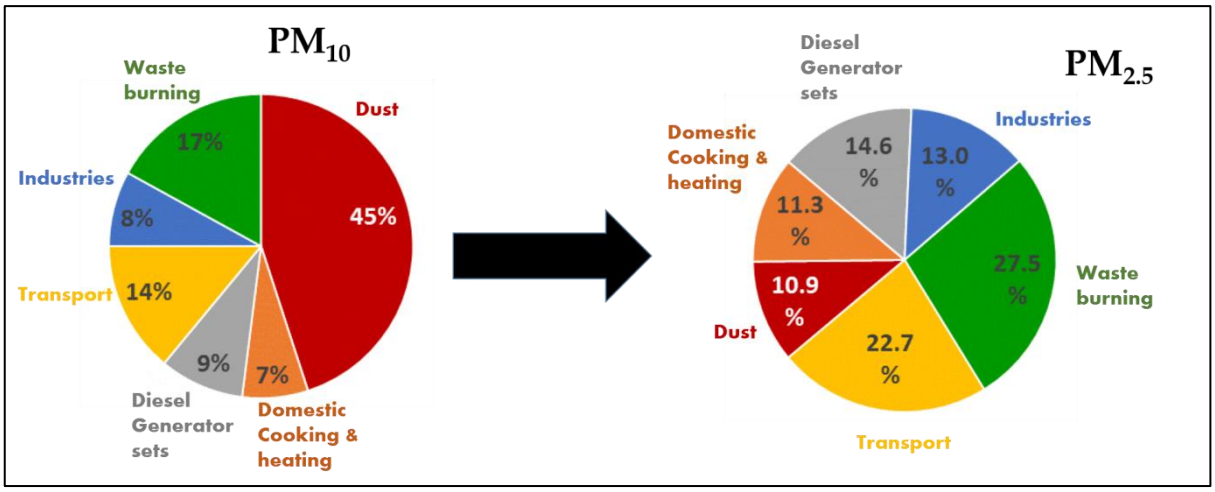

Fig.1.1 Source: CPCB, Delhi, (2010), report

1.3. The sources of PM_{10} and $PM_{2.5}$ contributing to ambient air quality in Delhi are different in summer, winter and monsoon.

- The winter sources (% contribution given in parenthesis for PM_{10} – $PM_{2.5}$ to the ambient air levels) include: secondary particles (25 - 30%), vehicles (20 - 25%), biomass burning (17 – 26%), MSW burning (9 - 8%) and to a lesser extent soil and road dust. It is noteworthy, in winter; major sources for PM_{10} and $PM_{2.5}$ are generally the same. A significant contribution in secondary nitrate is from vehicles. It is estimated that secondary nitrate particles of vehicles origin contribute to 3% of total $PM_{2.5}$ in ambient air that makes average vehicle contribution to $PM_{2.5}$ at about 28%.
- The summer sources (% contribution given in parenthesis for PM_{10} – $PM_{2.5}$ to the ambient air level) include: coal and fly ash (37 - 26%), soil and road dust (26 – 27%), secondary particles (10 - 15%), biomass burning (7 - 12%), vehicles (6 – 9%) and MSW burning (8 – 7%). It is noteworthy, in summer also, the major sources for PM_{10} and $PM_{2.5}$ are generally the same.
- The two most consistent sources for PM_{10} and $PM_{2.5}$ in both the seasons are secondary particles and vehicles. The other sources on average may contribute more (or less) but their contributions are variable from one day to another. Most variable source was biomass burning followed by MSW burning. Soil and road dust and coal and fly ash sources were consistent for PM_{10} but it was not true for $PM_{2.5}$

- Consistent presence of secondary and vehicular PM_{10} and $PM_{2.5}$ across all sites and in two seasons, suggests these particles encompass entire Delhi region as a layer.
- Similar to the above point, in summer, consistent presence of soil and road dust and coal and fly ash particles encompass entire Delhi region as a layer.
- Coal and fly ash and road and soil dust in summer contribute 26-37% to PM_{10} and $PM_{2.5}$. It is observed that in summer the atmosphere looks whitish to greyish indicating presence of large amounts of fly ash and dust; re-suspension of dust appears to be the cause of large contribution of these sources. This hypothesis can be argued from the fact that the contribution of fly ash and road dust reduces significantly both in PM_{10} and $PM_{2.5}$ in winter when winds are low and prevalent atmospheric conditions are calm.
- The contribution of the biomass burning in winter is quite high at 17% (for PM_{10}) 26% (for $PM_{2.5}$). Biomass burning is prohibited in Delhi and it is not a common practice at a large scale. The enhanced concentration of PM in October-November is possibly due to the effect of post-monsoon crop residue burning (CRB). It can be seen that the biomass contribution in PM_{10} in the month of November could be as high as 140µg/m^3 and about 120 µg/m^3 for $PM_{2.5}$ (mean of contribution in entire winter season: 97 µg/m^3 and 86 µg/m^3 respectively). In all likelihood, the PM from biomass burning is contributed from CRB prevalent in Punjab and Haryana in winter. The back trajectory analyses suggest that the CRB and other biomass emissions may be transported to Delhi from the sources upwind of Delhi (in NW direction). There is an immediate need to control or find alternatives to completely eliminate CRB emissions to observe significant improvement in air quality in Delhi. However, contribution of sizeable biomass burning to PM in December and January indicates to local sources present in Delhi and nearby areas.
- **Crop Residue burning in Punjab and Haryana**.

  Burning of agricultural biomass residue, or Crop Residue Burning (CRB) has been identified as a major health hazard. In addition to causing exposure to extremely high levels of Particulate Matter concentration to people in the immediate vicinity**,** it is also a major regional source of pollution, contributing

up to 60 % of PM concentrations as per various source apportionment studies. In addition, it causes loss of vital components such as nitrogen, phosphorus, sulphur and potassium from the topsoil layer, making the land less fertile and unviable for agriculture in the long run.

Fig.1.2.0 Crop Residue burning in Punjab and Haryana

1.4 Need for the Study

The report shows the seasonal variation of $PM_{2.5}$ in DTU campus, Delhi, India.

As per Indian census 2011, Delhi inhabitants' approximately 16.3 million people; thus becoming the second most populous city and second most populous urban agglomeration in India. Delhi is also the third largest urban area in the world. However, due to rapid development, Delhi is also facing serious challenges in terms of air pollution. To tackle the situation, Delhi has taken several steps to reduce the air pollution level during the last 10 years. However, more concerted efforts are still required to reduce the pollution level.

Evaluation of ambient air quality is a method to verify the effectiveness of the control measures implemented, and for early detection of potentially harmful changes in atmospheric composition. According to a detailed analysis of most of the criteria pollutants in Delhi, all criteria pollutants exceeded the National Ambient Air Quality Standards (NAAQS) applicable in INDIA. In this study, the period of interest is from 2017 to 2018. However, observed data available varies from site to site and from pollutant to pollutant. The pollutants studied are $PM_{2.5}$. Obviously, more observational sites at hot spot locations and residential areas are needed to adequately investigate the spatial variability and to provide a more comprehensive status of air quality in Delhi.

1.4.1 Earlier Studies

PM_{10} ,$PM_{2.5}$ and $PM_{1.0}$ concentrations varied seasonally with atmospheric processes and the anthropogenic activities in Delhi. PM_{10} decreases during monsoon by 25–80 $\mu g/m^3$ and $PM_{1.0}$ and $PM_{2.5}$ by 10–15 $\mu g/m^3$ from their pre-monsoon levels. Emissions were from fireworks during Deepawali in the post-monsoon season increases in PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ levels by 300 $\mu g/m^3$, 350 $\mu g/m^3$ and 400 $\mu g/m^3$, respectively over their monsoon levels (Tiwari et.al, 2012). The concentration of PAHs, SO_2, and CO shows decreasing trend after the implementation of CNG as an alternative fuel with to petrol or diesel fuelled vehicles, but an increase in NOx concentration was noticed. The concentrations of BTX, SPM and PM_{10} show no significant changes (Ravindra et al., 2006).

Several studies were done for the analysis of ambient air quality of Delhi city. One of the important analyses was done by CPCB (2010), which shows the snapshot of air quality at that time for Delhi city. On the basis of this project data, the ambient air quality of Delhi can be summarized below.

Delhi faces a severe air pollution problem due to the number of sources which are impacting the ambient air quality. Vehicular pollution in Delhi has grown from 64% to 72% from 1990 to 2000, whereas petrol and diesel consumption have grown by 400% and 300% respectively.

Other sources such as biomass burning refuse burning, construction dust and other unregulated sources are becoming major sources in some areas of high pollution levels.

Main pollutant which was covered in the CPCB study (CPCB, 2010) was carbon monoxide, 1-3 butadiene benzene, NMHC, aldehydes, alkanes, THC, PM_{10}, $PM_{2.5}$, ozone, PAHs, SPM, SO_2 and NO_2. Ambient air quality status in Delhi with respect to average concentration of major pollutants is presented in below Figure 1.1.

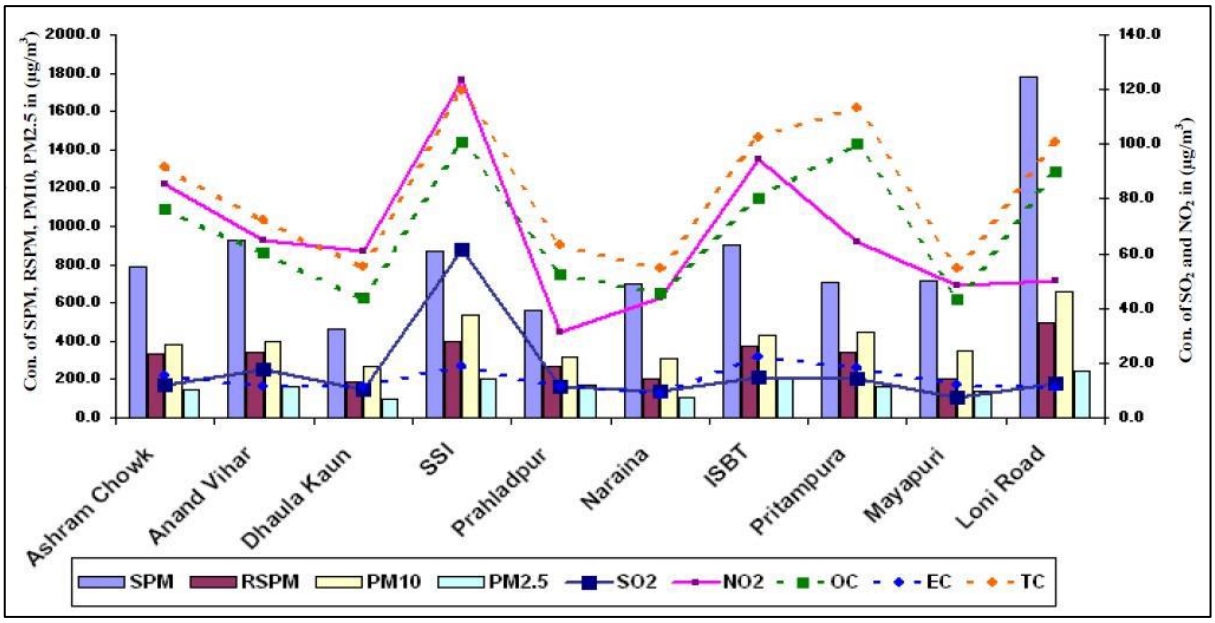

Fig1.3 Average Concentration of Particulate and Gaseous Pollutants at Ten Sites (Source: CPCB, 2010)

In the CPCB (2010) study, Prahladpur site was taken as a background site and it shows that the level of fine particulate matter and coarse matter exceeds the standard limit. In the same manner, remaining sites show similar trend for particulate pollution. It is noted that SPM concentrations were highest in Loni, followed by Anand Vihar, ISBT, SSI, whereas RSPM concentration were higher at Loni, SSI-GTK and ISBT. SSI-GTK is an industrial site shows high concentration of PM_{10} due to large scale industrial density as well as construction activities. Range of PM_{10} values at Pitampura and ISBT lies between 200-400 $\mu g/m^3$. Lowest value of PM_{10} concentration is in Dhaula Kuan. At all sites $PM_{2.5}$ concentrations exceeds the USEPA standard of 35 $\mu g/m^3$.

Another pollutant whose value exceeds the CPCB standard is a criteria pollutant NO_2 at the Kerb sites of ISBT and Ashram Chowk, which clearly shows the high movement of vehicles at these sites. Levels of NO_2 & SO_2 are in within the limit as per the CPCB norms in remaining all seven locations.

Level of total carbon (TC) and organic carbon (OC) shows highest value at SSI-GTK site. Value of OC is highest at Pitampura which indicates biomass burning at this site, whereas at Mayapuri, Naraina and Prahaladpur it shows lower values. SSI site shows higher OC concentrations followed by ISBT, Ashram Chowk, Pitampura and Loni Road, whereas lower at Mayapuri, Naraina and Dhaula Kuan. Higher EC concentration were

observed at ISBT, SSI and lowest at Naraina. Loni shows maximum OC/EC ratio followed by Anand Vihar, Naraina, Mayapuri and ISBT.

In the CPCB report (2010), it was observed that total PM emission is 147 ton/day; major contributor in PM is by Road dust which is approx. 52.5 % of total estimated pollution. Total NO_x and SO_2 emission was approximately 460t/d and 268t/d respectively; major contributors to these pollutants are Industries which account for 78.4% and 98.8% of total emission. Similarly CO and HC emissions is approx. 374 t/d and 131 t/d respectively and major contributor in this pollutant is by vehicles which is approx. 58.2% and 50.7%. Estimated quantity of the emissions from different sources is presented in Table 1.1

1.5 Project Objectives

The project aims to achieve the following:

(1) Measurement of mass concentration of $PM_{2.5}$ at DTU campus.

(2) Analysis and interpretation of data.

(3) Comparative analysis of the results with previous studies

(4) Compilation and interpretation of the past 3 years ambient air quality data at the specified sampling sites for $PM_{2.5}$.

1.7 Work approach

In this project report the work approach is to find the seasonal variation in mass concentration of $PM_{2.5}$ at sampling sites DTU Delhi, India with the help of EPAM5000 haz dust sampler which is provided by environmental engineering department lab (DTU). It has been tried to compare the result obtain during the experiment with previous years ambient air quality data which was provided by various eminent authors.

Over all the study is based on attainment of its objectives within the scope of work and broadly described in the project report.

1.8. Organization of the Report.

This report organized in following manner.

Chapter 1: Introduction

Chapter 2: Literature Review

Chapter 3: Methodology and materials.

Chapter 4: Results and Analysis

Chapter 5: Summary & Conclusions.

Chapter 2

LITERATURE REVIEW

2.1 Introduction

The main objective of this chapter is to perform literature survey which was published in previous years. This chapter is going to summarise the opinions of various authors related to $PM_{2.5}$ and PM_{10}. this chapter also describe the various sources of PM_{10} and $PM_{2.5}$ and their consequences on human beings, plants, animals and important monuments. This chapter also deals with the previous seasonal trends of PM_{10} and $PM_{2.5}$ at my sampling sites.

2.2 International Status

Until the conference on Human Environment held at Stockholm in 1972, the importance of environmental protection for improving the standard of living of human being was not realized. In 1991 at the World Commission on Environment held at Rio De Janeiro, the Heads of different countries met and decided to take immediate action to improve the Global Environment. In 1960, less than 22% of developing world's population was urban and the proportion increased to 34% by 1990. The projections are that 50% of the global population will be urban by 2020. The general state of the environment, including air quality, is deteriorating in many cities of the developing countries. World Bank studies in selected cities of developing countries have shown that swelling urban populations and the growth of industrial activities and automotive traffic in Asia has caused serious air pollution (World Bank, 2009). In India, the problem of air pollution has assumed serious proportions in most of the major metropolitan cities, where vehicular emissions contributed about 72% and industrial emissions about 20% to the ambient air pollution (Garg et al., 2001). Recent studies of the size and composition of atmospheric particulate matter (PM) have demonstrated the usefulness of separating atmospheric PM into its fine and coarse components. The need to measure the mass and composition of fine and coarse PM separately has been emphasized by research in exposure, epidemiology, and toxicology of atmospheric Particulate matters.

Zhao,Song,Wang, Zhao, and Zhu(2017) Done the works In China, residential areas which prevalently equipped with underground parking garages. Particulate matter has been confirmed as a major pollutant in garage spaces, and exposure to these particles, especially submicron and ultrafine particles, is closely associated with the health of vehicle owners and people who work in garages. In this study, we evaluated the seasonal patterns of $PM_{10,}$ $PM_{2.5}$ and $PM_{1.0}$ in a naturally ventilated underground residential parking garage using field measurements collected at various times over a one-year period. The impacts of traffic flow, air exchange rate, and outdoor particles were determined by employing Pearson correlation and a mass-balance model. The results showed significant seasonal diurnal patterns of PM_{10}, $PM_{2.5}$ and $PM_{1.0}$, with maximum values during winter and minimum values during summer. The daily mean PM_{10} and $PM_{2.5}$ in the garage exceeded the long-term (24 h) exposure limit of the Chinese standard (0.15 mg/m^3 for PM_{10} and 0.075 mg/m^3 for $PM_{2.5}$) during spring, fall and winter, with the highest PM_{10} and $PM_{2.5}$ concentration exceeding the limit eightfold. Use of natural ventilation only in the residential underground parking garage could not guarantee that particle pollution was at a "safe" exposure level in the study. During the measurements, the hourly mean PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ appeared to vary linearly under the combined effects of the air exchange rate multiplied by the outdoor particles; traffic flow; and mean PM_{10}, $PM_{2.5}$ and $PM_{1.0}$ during the past hour.

Aziz, Ali et.al,(2015) revealed that transport microenvironments can contain higher levels of particulate matter due to infiltration from the roads, vehicular exhaust and commuter's activities. The present study monitored PM, CO_2, CO, temperature and relative humidity levels in diesel-powered buses in Pakistan and United Kingdom. Two routes of almost the same travelling distance were selected in Pakistan and the UK. Indoor air quality of the buses was monitored to determine the exposure faced by the commuters on inter-city journeys. While the observed levels in both countries were not in compliance with the WHO guidelines, levels of particulate matter were much higher in Pakistan than the concentrations in UK.

Cheng, Liu, and Yan (2012) showed that Commuters spend considerable time, in some cases up to 1–2 h /day, traveling in metro trains. However, few studies have compared air quality between trains traveling above-ground and underground. This study measures the PM_{10} and $PM_{2.5}$; particle number (PN) and CO_2 levels inside

metro trains traveling in underground tunnels and on elevated tracks on a metro line in the Taipei metro system. The results demonstrated that PM_{10} and $PM_{2.5}$ and CO_2 levels inside metro trains traveling in underground environments are approximately 20–50% higher than those in above-ground environments. However, PN levels inside metro trains traveling in underground environments are approximately 20% lower than those in above-ground ones. These measurement results reveal that levels of pollutant species inside the metro trains are significantly affected by traveling environmental conditions—in underground tunnels or on elevated tracks. Moreover, the levels of pollutant species inside the metro trains traveling on the same route are also different in different traveling directions. Fine PM inside the metro trains is transferred from the outside and significantly influenced by the surrounding conditions of the trains. Additionally, a high fraction of large coarse PM (> 10μm) is observed inside the metro trains, possibly due to re-suspension by the movement of commuters. The measurement results show that, unlike PM, which is transferred from outside environments, CO_2 inside metro trains is elevated internally by exhalation from commuters. Clearly, CO_2 exhaled by commuters could accumulate inside metro trains and, compared to PM, is not as easily removed by the ventilation system when air circulation does not provide enough fresh air in the metro trains, particularly in trains traveling in underground environments.

Banerjee et al., 2011; Sharma et al (2003) showed that PM_{10} levels in Indian cities have been found in the range of 100-400 $\mu g/m^3$.

Reddy and Venkataraman (2002) showed that a comprehensive, spatially resolved fossil fuel consumption database and emissions inventory was constructed, for India, for the first time. Emissions of sulphur dioxide and aerosol chemical constituents were estimated for 1996–1997 and extrapolated to the Indian Ocean Experiment (INDOEX) study period (1998–1999). District level consumption of coal/lignite, petroleum and natural gas in power plants, industrial, transportation and domestic sectors was 9411 PJ, with major contributions from coal (54%) followed by diesel (18%). Emission factors for various pollutants were derived using India specific fuel characteristics and information on combustion/air pollution control technologies for the power and industrial sectors. Domestic and transportation emission factors, appropriate for Indian source characteristics, were compiled from literature. SO_2

emissions from fossil fuel combustion for 1996–1997 were 4.0Tg SO_2 /year, with 756 large point sources (e.g. utilities, iron and steel, fertilisers, cement, refineries and petrochemicals and non-ferrous metals), accounting for 62%. $PM_{2.5}$ emitted was 0.5 and 2.0Tg/year for the 100% and the 50% control scenario, respectively, applied to coal burning in the power and industrial sectors. Coal combustion was the major source of $PM_{2.5}$ (92%) primarily consisting of fly ash, accounting for 98% of the ''inorganic fraction'' emissions (difference between $PM_{2.5}$ and black carbon organic+ matter) of 1.6Tg/yr. Black carbon emissions were estimated at 0.1Tg/year, with 58% from diesel transport, and organic matter emissions at 0.3Tg/year, with 48% from brick-kilns. Fossil fuel consumption and emissions peaked at the large point industrial sources and 22 cities, with elevated area fluxes in northern and western India. The spatial resolution of this inventory makes it suitable for regional-scale aerosol-climate studies. These results are compared to previous studies and differences discussed. Measurements of emission factors for Indian sources are needed to further refine these estimates.

Shukla and Sharma, (2008) applied simple source apportionment technique, factor analysis, multiple regression to apportion the sources of PM_{10} at a relatively less polluted site in Kanpur, India. In three seasons studied, two important PM_{10} sources were soil-road dust (15-47%) and inorganic secondary particles like $(NH_4)_2SO_2$ and NH_4NO_3 (21-26%). They concluded that $NH^{4-}$is a far more dominating ion responsible for secondary particle formation; thus, the role of ambient ammonia is most vital in overall atmospheric chemistry of particulate formation.

Schroeder et al. (1987) has reported 30–35 heavy metals in atmospheric PM. Manganese, copper, zinc, cadmium, chromium, iron, nickel, potassium, calcium, vanadium, barium, arsenic, selenium and strontium are the most commonly found metals in the pollution sources and have been studied widely. Metals associated with the finer fraction mostly originate from the incomplete combustion of carbon-containing materials from motor vehicles, power plants, smelters, incinerators, cement kilns and home furnaces. The metals derived from natural sources are usually present in the coarse fraction. Re-suspension of roadside dust and soil is another potential source of heavy metals.

Biswas, Upadhyay, Nayak and Yadav(2011) Analysed 1-hour, 8-hour and 24-hour averaged criteria pollutants (NO_2, SO_2, CO, $PM_{2.5}$ and PM_{10}) during 2004-2009 at three observational sites *i.e.* Income Tax Office (ITO), Sirifort and Delhi College of Engineering(DCE) in Delhi, India. The analysis reveals increased pollutant concentrations at the urban ITO site as compared to the other two sites, suggesting the need to better locate hot spots in designing the monitoring network. There is also significant year to year variation in the design value trends of criteria pollutants at these three sites, which may be attributed to meteorological variations and local-level emission fluctuations. Correlations among criteria pollutants vary annually and spatially from site to site, indicating the heterogeneous nature of air mix. The annual ratios of CO/NO_x are considerably higher than SO_2/NO_x confirming that vehicular source emissions are the primary contributors to air pollution in Delhi. The seasonal analysis of criteria pollutants reveals relatively higher concentrations in winter because of limited pollutant dispersion and lower concentrations during the monsoon period (rainy season). The diurnal averages of criteria pollutants reveal that vehicular emissions strongly influence temporal variations of these pollutants. Weekdays and weekend diurnal averages do not show noticeable differences.

Tiwari, Srivastava, Bisht and Padmanabhamurty(2012) showed that Daily, monthly, seasonal and annual moving means of $PM_{1.0}$, $PM_{2.5}$ and PM_{10} concentrations from August, 2007 to October, 2008 at Delhi (28º 35' N; 77º 12' E),the seventh populous megacity in the world are presented. $PM_{1.0}$, $PM_{2.5}$ and PM_{10} concentrations varied seasonally with atmospheric processes and the anthropogenic activities. PM_{10} decreases during monsoon by 25–80 $\mu g/m^3$ and $PM_{1.0}$ and $PM_{2.5}$ by 10–15$\mu g/m^3$ from their pre-monsoon levels. Emissions from fireworks during Deepawali in the post-monsoon season increases $PM_{1.0}$, $PM_{2.5}$ and PM_{10} levels by 300 $\mu g/m^3$, 350 $\mu g/m^3$ and 400 $\mu g/m^3$, respectively over their monsoon levels. Seasonal variation of mixing heights, temperatures, winds and rainfall, accounts for the inter-annual variability of $PM_{1.0}$, $PM_{2.5}$ and PM_{10}. Accordingly, wintertime $PM_{1.0}$, $PM_{2.5}$ and PM_{10} components contribute by 30–33% to annual levels. PM_{10} in summer is higher by 8% to that of $PM_{2.5}$ and by 9% to that of $PM_{1.0}$ and PM_{10} components in post-monsoon are lower by 5% to that of $PM_{2.5}$ and by 7% to that of$PM_{1.0}$. Also, $PM_{1.0}$, $PM_{2.5}$ and PM_{10} levels were higher during October, 2008 than those in 2007, but their levels were almost remaining the same in August and September of 2007

and 2008. Moving means of $PM_{1.0}$, $PM_{2.5}$ and PM_{10} and their concentrations in different seasons are useful in policy making decisions thereupon aiming to improve the air quality in Delhi.

Massey, Kulshrestha, Masih and Taneja(2011) Presented data on the size characterization concentration of $PM_{1.0}$, $PM_{2.5}$ and $PM_{10.}$ These particulate concentrations were monitored from October-07 to March-09 indoors and outdoors of five roadside and five urban homes using Grimm aerosol spectrometer in Agra, India. Annual average concentrations of coarse particles (PM_{10}) indoor and outdoor were 247 mg/m^3 and 255 mg/m^3 at roadside houses and 181 mg/m^3 and 195 mg/m^3 at urban houses. $PM_{2.5}$ concentrations at roadside houses were 211 mg/m^3 and 230 mg/m^3 and at urban houses were 145 mg/m^3 and 159 mg/m^3. For fine particles ($PM_{2.5}$) the annual mean concentrations were 161 mg/m^3 and 160 mg/m^3 at roadside houses and 109 mg/m^3 and 123 mg/m^3 at urban houses. $PM_{1.0}$ concentrations at roadside houses were 11 mg/m^3 and 112 mg/m^3 while at urban houses they were 99 mg/m^3 and 104 mg/m^3.Monthly and seasonal variations of coarse and fine particulate matter have been studied at both the monitoring sites. Significant seasonal variations of particulate pollutants were obtained using the daily average particulate concentrations along with the inter particulate ratios. Particulate indoor/outdoor ratios and concentrations were also linked with meteorological conditions and indoor activities using occupant's diary entries. The concentration of all sizes of particulate matter was found to be highest in winter season due to increase human activities and more space heating in indoors and due to low wind speed and high humidity in outdoors in comparison with other seasons. There was a strong correlation between indoor and outdoor particulate at both the sites.

Health problems in occupants of the houses with higher concentrations of the fine particulate matter were more prominent. Household activities like cooking on stoves, indoor smoking and outdoor vehicular traffic, and garbage burning were found to be the major sources of particulate emissions indoor as well as outdoors.

Srivastava and Jain (2006) Revealed a study of the atmospheric particulate size distribution of total suspended particulate matter (TSPM) and associated heavy metal concentrations has been carried out for the city of Delhi. Urban particles were collected using a five-stage impact or at six sites in three different seasons, viz.

winter, summer and monsoon in the year 2001. Five samples from each site in each season were collected. Each sample (filter paper) was extracted with a mixture of nitric acid, hydrochloric acid and hydrofluoric acid. The acid solutions of the samples were analysed in five-particle fractions by atomic absorption spectrometry (AAS). The impact or stage fractionation of particles shows that a major portion of TSPM concentration is in the form of PM0.7 (i.e. <0.7 lm). Similarly, the most of the metal mass viz. Mn, Cr, Cd, Pb, Ni, and Fe are also concentrated in the PM0.7 mode. The only exceptions are size distributions pertaining to Cu and Ca. Though, Cu is more in PM0.7 mode, its presence in size intervals 5.4–1.6 lm and 1.6–0.7 lm is also significant, whilst in case of Ca there is no definite pattern in its distribution with size of particles. The average $PM_{10.9}$ (i.e. <10.9 lm) concentrations are approximately 90.2% ± 4.5%, 81.4% ± 1.4% and 86.4% ± 9.6% of TSPM for winter, summer and monsoon seasons, respectively. Source apportionment reveals that there are two sources of TSPM and $PM_{10.9}$, while three and four sources were observed for $PM_{1.0}$ (i.e. <1.6 lm) and $PM_{0.7}$, respectively. Results of regression analyses show definite correlations between $PM_{10.9}$ and other fine size fractions, suggesting $PM_{10.9}$ may adequately act as a surrogate for both $PM_{1.6}$ and $PM_{0.7}$, while $PM_{1.6}$ may adequately act as a surrogate for $PM_{0.7}$.

Wei ,Yang Lu and Wentao Wu (2015) Showed that $PM_{2.5}$ and PM_{10} attach harmful substance easily and they pose a threat to health after being inhaled. Here deposits a large amount of $PM_{2.5}$ and PM_{10} in the air conditioning system pipe surface, and they seriously affect the indoor air quality following by air into the room. This article analyses the diffusion and propagation characteristics of $PM_{2.5}$ and PM_{10} in the ventilation duct. The study focus on particles in the viscous sub layer and analyses its movement. The study shows that the larger the wind speed, the faster particles reaching stable distribution; The velocity change of particles increases sharply, then decreases, remains stable finally; The final velocity (X direction) of particles of different size is same basically in the same duct with the same initial velocity(X direction); $PM_{2.5}$ and PM_{10} are generally deposited on the bottom of the pipe within the range of the allowable wind velocity in the air conditioning system. Therefore, the paper concludes that in order to prevent the $PM_{2.5}$ and PM_{10} harm to the human, we should clean the ventilation duct regularly.

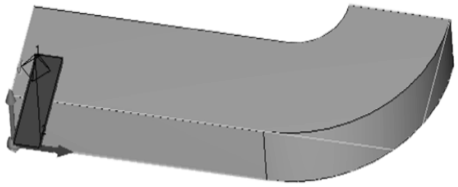

Fig.2.1 (a) straight pipe model	(b) bend pipe model

Duan, Chen, Fang and Zhengjun Su (2015) showed that Ground measurements of particulate matter (PM), $PM_{2.5}$ and PM_{10} were recorded using a ten-channel Quartz Crystal Microbalance (QCM) Cascade Impact or in a polluted city, Shijiazhuang, northern China for the period Jan. – Mar. and Jun. 2007. The spectra characteristics in the concentrations of PM are analysed. $PM_{1.0}$, $PM_{2.5}$ and PM_{10} monthly variations are researched. PM mass concentration is similar with Beijing and four times higher than some clean sites. Mass and number concentration relationships between $PM_{2.5}$ and PM_{10} are analysed and calculated. The mass concentration ratio of $PM_{2.5}$ to PM_{10} is 0.7. The ratio of the number concentration to mass concentration of $PM_{2.5}$ is 76,419. These relationships are used to calculate $PM_{2.5}$ number concentration by PM_{10} mass concentration for daily publication observation. Then the diurnal variation of $PM_{2.5}$ number concentration is analysed from Jan. – Mar. 2007. This attempt provides a new way to analysis fine particles feature by using regular daily observations of PM_{10}.

Ding, Zhang, Sun, and Feng (2015) In order to investigate the transfer characteristics of $PM_{2.5}$ in a car-cabin, several experiments were done through real-time online monitoring the concentration of $PM_{2.5}$ and CO_2 in the car-cabin under different ventilation modes (Circulation with the outdoor air and Recirculation without fresh air) under the minimum of mechanical ventilation and the same experimental route condition. $PM_{2.5}$ concentration distribution characteristics and the ratio of inside to outside concentration I/O were analysed. The ventilation rate was

determined by the CO_2 concentration change during the experiment and further was used to analyse the transfer characteristic of $PM_{2.5}$. The results showed that under the circulation with the outdoor air condition, average I/O is 0.6, while it is 0.25 under recirculation condition. I/O value increases with the increase of the driving speed. It could be concluded that ventilation mode have a significant impact on the cabin concentration of $PM_{2.5}$ and plays a decisive role in $PM_{2.5}$ levels in the car-cabin. The quantitative evaluation $PM_{2.5}$ transfer characteristic analysis under circulation with outdoor air condition shows that the ventilation, penetration and deposition accounted for 69.3%, 22.8%, and 7.9%, respectively. While under recirculation condition, penetration accounted for 72%, and deposition accounted for 28%.

2.4. Trends of Particulate Matter (PM):PM_{10} and $PM_{2.5}$ in Indian cities.

PM levels in Indian cities are about 4-5 times higher than in the US cities (WRI, 1996). These high PM levels may have severe impact on public health. The sixteen-year long survey by Dockery *et al.*(1994) has revealed that there is a strong correlation between ambient PM concentrations and increase in mortality and hospitalizations due to respiratory diseases. Several epidemiological studies (Pope, 1989; Schwartz, 1996) have linked PM_{10} (aerodynamic diameter $\leq$ 10μm) and $PM_{2.5}$ (aerodynamic diameter $\leq$2.5μm) with significant health problems, including: premature mortality, chronic respiratory disease, emergency visits and hospital admissions, aggravated asthma, acute respiratory symptoms, and decrease in lung function. $PM_{2.5}$ is of specific concern because it contains a high proportion of various toxic metals and acids, and aerodynamically it can penetrate deeper into the respiratory tract.

A HEI study, (Wichmannet al., 2000) reported that the concentration of both ultrafine (PM<0.1) and fine particles (PM0.1-2.5) was associated with increased daily mortality. Lippmann et al. (2000) reported that four of five size fractions (PM_{40} PM_{10-40} PM_{10} $PM_{2.5-10}$ $PM_{2.5}$) were associated with increased in morbidity and mortality. The largest particle size fraction (10 μm – 40 μm) was not associated with increased morbidity and mortality. However, Castillejos *et al.* (2000) in Mexico City and Ostro

et al. (2000) in western United States have found health effects being associated with the coarse fraction as well but studies (Schwartz *et al.*, 1996) conducted in other

parts of the United States and in Canada have reported that effects of fine particles are predominant.

Major concerns for human health from exposure to PM_{10} include effects on breathing, respiratory symptoms, decrease in pulmonary function and damage to lung tissue, cancer, and premature death. An association between elevated PM_{10} levels and hospital admissions for pneumonia, bronchitis, and asthma was observed by Pope (1989). Long-term particulate exposure was associated with an increase in risk of respiratory illness in children (Dockery *et al.*, 1989). Statistically significant relationships were observed between TSP levels and forced vital capacity (FVC) and FEV1 (Chestnut *et al.*, 1991). Ostro (1993) has reported a series of studies that observed associations between daily changes in particulate pollution and daily mortality. Prospective cohort studies by Pope *et al.* (1995) observed 30 to 50% increase in lung cancer rates associated with exposure to respiratory particles. Associations between mortality risk and air pollution were strongest for respiratory particles and sulphates (Pope et.al., 1995). PEFR (peak expiratory flow rate) and respiratory symptoms were strongly associated with PM_{10} levels and marginally with ozone levels (Romeo et al., 1996). Increase in PM concentration correlated with increase in mortality and morbidity rates. An increase of $10\mu g/m^3$ of PM_{10} levels resulted in a 3-6 % increase in visits for asthma people and a 1-3 % increase in visits for upper respiratory diseases not with asthma to hospitals. The findings are consistent with the result of previous studies of particulate pollution in other urban areas and provide evidence that the coarse fraction of PM_{10} may affect the health of working people (Gordian et al., 1996). A study in six US cities has shown that there is an association between fine particulate matter ($PM_{2.5}$) primarily from combustion sources and daily mortality (increase in Schwartz *et al.*, 1996). Combustion particles in the fine fraction from mobile and coal combustion sources, both not fine crustal particles, are associated with mortality (Laden et al., 2000).

Sharma et al. (2004) through a study in Kanpur reported that mean PEF (L/min) values of a cohort (of over 100 subjects) decrease with the increase in PM_{10} and/or $PM_{2.5}$. The findings of the study can be summarized as under:

(i) The correlation (negative) between mean ΔPEF (i.e. deviation in PEF) of a day (no. of days of sampling = 39) and four indicators of PM levels (PM_{10}, $PM_{2.5}$), PM_{10} (one-day lag) and $PM_{2.5}$ (one-day lag)) was found to be statistically significant ($p < 0.05$). It showed that as the pollution level increases the lung function in terms of

PEFR reduces/deteriorates. The negative correlation with PM_{10} (one day lag) and $PM_{2.5}$ (one-day lag) also suggested that PM pollution may have sustained effect on PEFR value due to pollution level of previous day.

(ii) PM_{10} and $PM_{2.5}$correlate with ΔPEF, PM_{10} and their concentration levels are better indicator to reflect changes in PEFR values. This suggests that the deposition of larger particles (PM_{10}) takes place in upper part of respiratory system that activates mucus secretion resulting is constriction of airways and thus lowering PEFR value. The fine particles impact the pulmonary region (lower respiratory system), which are known to cause long-term chronic effects.

(iii) FEV1, PEFR and FVC are the key lung function parameters that reflect health impact of air pollution (Bates, 2002). The deviations found in FEV1 and FVC are: (a) FEV1 -0.30 L (at Vikas Nagar (VN): PM_{10}: 300μg/m3), -0.31 (at Juhi Colony (JC): PM_{10}: 300 $\mu g/m^3$) and -0.18 L (IIT Kanpur (IITK): PM10: 185 $\mu g/m^3$ IITK) and (b) FVC -0.42 L (VN), -0.40 (JC) and -0.27 L (IITK).

It is evident from the above discussion that both PM_{10} and $PM_{2.5}$ have specific health impacts and both of these pollutants should be considered for AQI.

PM_{10}

WHO (2005) suggests that there is no threshold for particulate concentration below which there is no harmful effect. At the same time, high PM_{10} background concentration in India cannot be disregarded which is reflected in relatively high level of INAQS for PM_{10}; Sharma (2009) has estimated background concentration of PM10 as 35 μg/m3. For PM_{10}, in view of no specific studies in India, it is proposed that the breakpoints proposed by USEPA may be adopted after accounting for INAQS table 2.1.

Table 2.1 Breakpoints Concentration (B.P CONC.)For PM_{10} ($\mu g/m^3$)

INDIA (24-hr)		US(24-hr)		CHINA(24-hr)		EU(24-hr)	
AQI category	B.P CONC.	AQI Category	B.P CONC.	AQI Category	B.P CONC.	AQI category	B.P CONC.
Good	50	Good	55	Excellent	50	Very low	15
Satisfactory	100	Moderate	155	Good	150	Low	30
		Unhealthy for		Lightly polluted		Medium	50

Moderate	250	sensitive group	255		250		
Poor	350	Unhealthy	355	Moderately polluted	350	High	100
Very poor	430	Very unhealthy	425	Heavily polluted	420	Very high	100+
Severe	430+	Hazardous	425+	Severely polluted	420+		

$PM_{2.5}$

Sharma (2009) has estimated background concentration of $PM_{2.5}$ as 17-28 μg/m^3. The background concentration in Europe and the US is very low (< 5 μg/m^3). Therefore, for lower concentration range, it is not reasonable to follow the breakpoints as proposed by US or EU. With due regard to INAQS (which accounts for background pollution), the first two categories, Good and Satisfactory, the breakpoints are kept as 30 and 60 μg/m^3. As per HEI Global Burden of disease report (2013), till 90μg/m^3 the relative risk of Ischemic Heart Disease increase and then more or less it plateaus off, therefore the next break point for category moderate is kept as 90μg/m^3. For $PM_{2.5}$, in view of no specific studies in India, it is proposed that the breakpoints proposed by USEPA may be adopted. Beyond first three categories, the breakpoints proposed by USEPA and China are adopted (table 2.2)

Table 2.2 Breaking points Concentration (B.P CONC.) Of $PM_{2.5}$ (μg/m^3)

INDIA (24-hr)		US(24-hr)		CHINA(24-hr)		EU(24 hr)	
AQI category	B.P CONC.	AQI Category	B.P CONC.	AQI category	B.P CONC.	AQI category	B.P CONC.
Good	30	Good	12	Excellent	35	Very low	10
Satisfactory	60	Moderate	35	Good	75	Low	20
Moderate	90	Unhealthy for sensitive group	55	Lightly polluted	115	Medium	30
Poor	120	Unhealthy	150	Moderately polluted	150	High	60
Very poor	250	Very unhealthy	250	Heavily polluted	250	Very high	60+
Severe	250+	Hazardous	250+	Severely polluted	250+		

Chapter 3

MATERIALS AND METHODOLOGY

This chapter discusses different experimental necessities for determination of $PM_{2.5}$ of the study area. This chapter also describes about the methodology which adopted during experiment. It also includes the fine points and supportive important information which is required for the experimental findings. This chapter gives complete overview of model EPAM-5000.This chapter (i) Introduces and describes EPAM-5000.

(ii) Explains operating principle of EPAM-5000. (iii) Identifies features and specifications and components of EPAM-5000.

3.1 Study Area. The experiment was carried out in DTU campus whose geographical location is **28°44′59.81″N and 77°7′1.30″E**. The whole experiment was divided into four phases. I.e. in monsoon (August to September 2017), Post monsoon (October to November 2017), winter (December-2017 to January-2018) and summer (April to May 2018). The experiment was performed daily from 12 pm to 4pm except holiday in DTU calendar and average concentration of four hour of $PM_{2.5}$ is calculated daily.

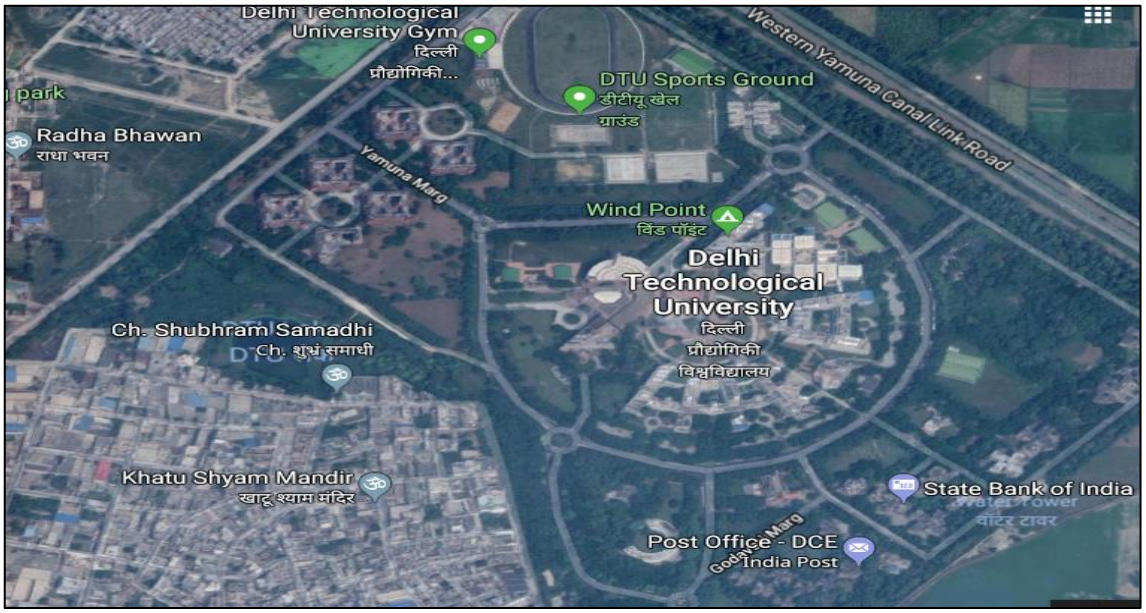

Fig. 3.1 Satellite image of site location (DTU, Delhi)

3.2. Description of instrument and Introduction to the EPAM-5000

The EPAM-5000 is a high sensitivity real-time particulate monitor designed for ambient environmental and indoor air quality applications. This unit combines traditional filter techniques with real-time monitoring methods. These techniques combined overcome limitations of all other aerosol monitoring products.

Principles: The EPAM-5000 uses the principle of near-forward light scattering of an infrared radiation to immediately and continuously measure the concentration in mg/m^3 of airborne dust particles.

• This principle utilizes an infrared light source positioned at a 90-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.

• A unique signal processes internally and compensates for noise and drift. This allows high resolution, low detection limits and excellent base line stability.

Fig.3.2 EPAM5000 haz Dust

3.2.1Introduction:

TheEPAM-5000 provides a unique combination of features to provide superior data quality, ease of use, and flexibility to the user. The EPAM-5000 is a high sensitivity real-time particulate monitor designed for ambient environmental and indoor air quality applications. This unit combines traditional filter techniques with real-time monitoring methods. These techniques combined overcome limitations of all other aerosol monitoring products.

Comparison of Methods

The traditional and real-time dust monitoring methods are described below.

Description of traditional method

Air is drawn by a vacuum pump through a 47mm diameter membrane filter EPA FRM Style. The fibres and particlescollected on the membrane filter must be counted or weighed in a laboratory for further analysis.

Advantages of traditional method

- EPA or OSHA compliance reference method.
- High level of specificity and accuracy.
- Collection of dust particles, which are available for further chemical analysis.

Description of real time method

Dust particles are drawn into the sensor head and are detected once every second. Dust concentrations are instantaneously calculated and displayed on the SKC EPAM-5000's LCD. All data points are stored in memory for later analysis

Advantages of real time method

- Immediate estimations of the concentration of a contaminant, permitting on-site evaluations.
- Provision of permanent 24-hour records of contaminant concentrations using continuous monitors.
- Internal audible alarm to warn workers of approaching hazardous situations.
- Reduction of number of manual filter tests.
- Reduction of number of laboratory analyses.

- Provision of more convincing evidence for presentation at hearings and litigation proceedings.
- Reduced cost of obtaining individual results

3.2.2. Overview of the EPAM-5000

Ease of use

- The user controls all functionality and programming using menus displayed on a high contrast LCD.
- A 6-hour rechargeable battery capacity.
- Internal temperature compensation for ambient use.

General information

- The LCD displays real-time concentration in milligram per cubic meter (mg/m^3) in accordance with EPA or OSHA Reference Methods.
- Statistical information of TWA, STEL, Max and Min levels can be viewed instantly. The EPAM-5000 is calibrated using Arizona Road Dust (ARD) against NIOSH method 0600 for Respirable dust with±10% accuracy.
- The calibration of the SKC EPAM-5000 can be adjusted to compensate for changes in particle composition and distribution

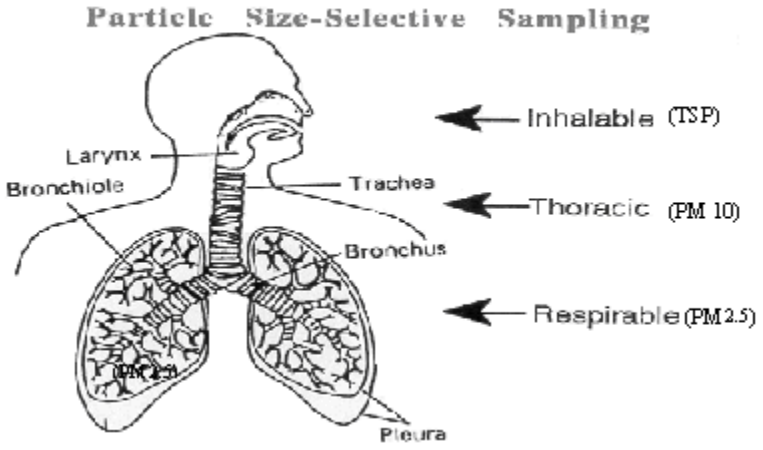

Fig.3.3 Diagram showing breathing zones of Inhalable, Thoracic, and Respirable dust particles. (source : EPAM5000 manual)

Dust cum pro software

Dust Cum Pro supplied software is designed for more detailed analysis of sampled data. Pull down menus provide for a user friendly environment to store and analyse data and print management ready reports .Data can easily be exported in comma-delimited ASCII Text Files importable into spread sheet programs such as Microsoft Excel and Lotus 1-2-3. Dust Cum Pro Software is used for downloading the information on Windows XP, 2000, NT, and ME PCs.

The data plots provided with Dust Cum Pro enable:

Detailed statistical analysis

Creation of graphics and charts

Mathematical correction of particle characteristics when aerosol significantly differs from calibration dust

3.2.3. Real time dust monitoring principles

(i) The EPAM-5000 uses the principle of near-forward light scattering of an infrared radiation to immediately and continuously measure the concentration in mg/m^3 of airborne dust particles.

(ii) This principle utilizes an infrared light source positioned at a 90-degree angle from a photo detector.

(iii) 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.

(iv) A unique signal processes internally and compensates for noise and drift. This allows high resolution, low detection limits and excellent base line stability.

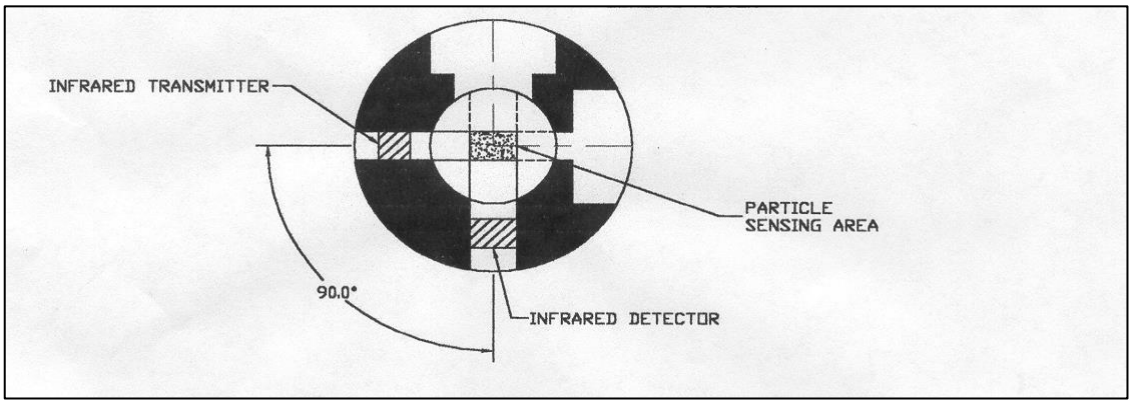

Fig.3.4 Diagram showing the principle of near-forward light scattering used in the EPAM-5000 (Source: EPAM 5000 manual)

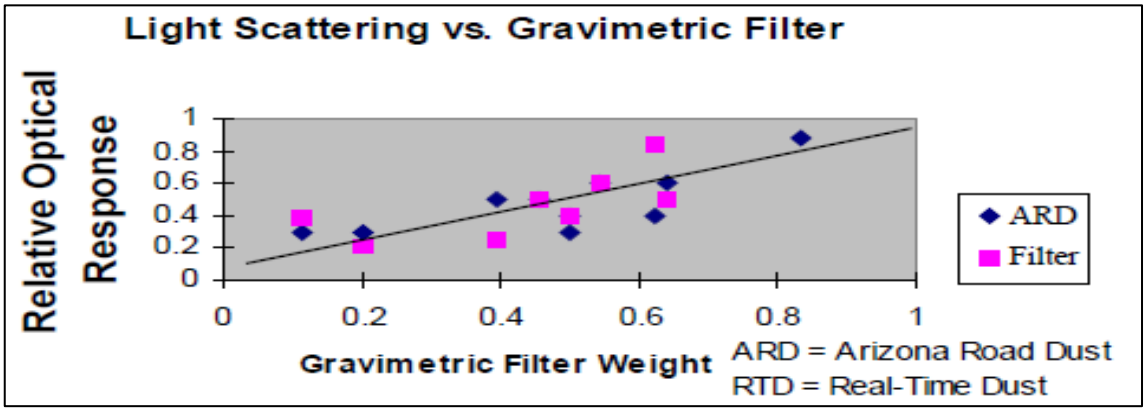

Fig.3.5 Graph illustrating the principle of near-forward light scattering

(Source: EPAM 5000 manual)

3.2.4. Features

Introduction: The EPAM-5000 provides a unique combination of features to provide superior data quality, ease of use, and flexibility to the user. Below is a partial list of distinctive features

Real-time display of:

• Particulate exposure levels.

•STEL, Min, and Max levels.

• $PM_{1.0}$, $PM_{2.5}$, PM_{10}, or TSP.

• Stored data by location code.

Functional features:

- Calibrated to NIOSH methods for lung damaging particles.
- In line concurrent filter samples for gravimetric analysis.
- High sensitivity of 0.001 to 20 mg/m^3 (1 $\mu g/m^3$- 2000 $\mu g/m^3$).
- Interchangeable size-selective sampling inlets.
- Internal air sampling pump. Auto purging sensor.
- Easy user access to rechargeable battery and internal filter.

Operational features:

- On-screen programming of sampling and data storage parameters.

- Real-time clock.
- User selectable audible alarm.
- In-field zero and span check of instrument calibration. **Data management:**
- Choice of 1 second, 1 minute, 10 second, or 30 minute averaging/storage intervals.
- Up to 15 months of sample/record time.
- Memory storage of up to 21,600 data points, which can be, distributed into a maximum of 999 location files.
- Data translation to ASCII text files, importable into Excel or Lotus 1-2-3.
- Dotcom Pro software offers comparative graphical and statistical analysis.

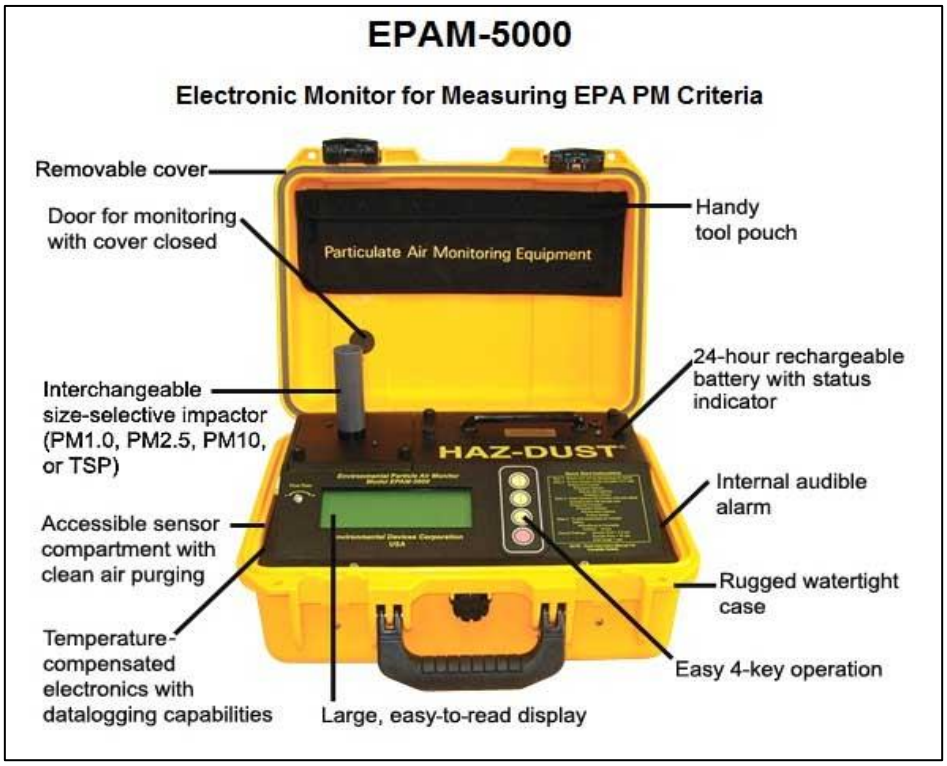

Fig.3.6 Details of EPAM5000

3.2.5. Components

The following components included with the EPAM-5000.

- EPAM-5000 Monitor.
- Rechargeable battery pack.
- Battery charger.
- Trimming tool.
- EPAM Media CD-ROM Includes: Dust Comm Pro Software and Instruction Manual.
- RS232 9-pin serial cable (female to male).
- TSP Sampling inlet (1.0 µm, 2.5 µm, or 10 µm sampling inlet optional.
- Flow Audit Measuring Device Adapter
- Flow Audit Measuring Device.

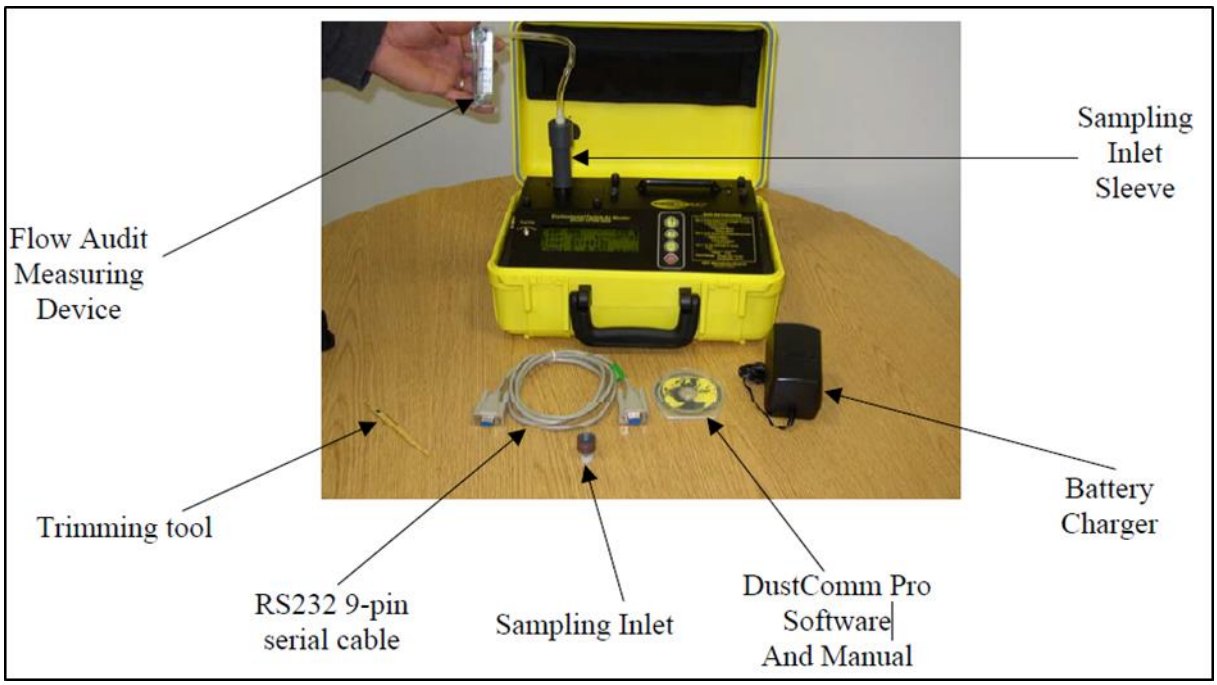

Fig.3.7 Components of EPAM-5000 (Source: EPAM 5000 manual)

3.3. Operating Parameters of the EPAM-5000

This chapter describes the steps involved in starting the EPAM-5000 and configuring its operating parameters.

3.3.1. Turning the EPAM-5000 on and Off

Introduction: Power can be supplied to the EPAM-5000 either from its internal battery or from the provided AC power transformer (Battery Charger). Press the ON/OFF key to turn the EPAM-5000 monitor on. Press the ON/OFF key a second time to turn the EPAM-5000 off.

Fig.3.8 Key pad on EPAM-5000

3.3.2 Setting the Date and Time

The date and time are pre-set by the factory to Eastern Standard Time and are maintained by an internal clock. It may be necessary to change the date and time due to local time zones or daylight savings time. Time is entered and displayed in military time format. Date is entered and displayed in European format (i.e., MON 04-JUNE-18).

View settings:

Follow the steps in the table to below to check unit's date and time.

Table 3.1 Setting the Date and Time

steps	Action
1	Select **special functions** from the mainmenu
2	Select **date/time**
3	Select **view date/time**
4	Press **ENTER** to returnview date/time screen

3.3.3. Change settings

Follow the steps in the table below to change unit's date and time.

Table 3.2 Change settings

<table>
<tr><td>Steps</td><td>Action</td></tr>
<tr><td>1</td><td>Select special function from the main menu</td></tr>
<tr><td>2</td><td>Select date and time</td></tr>
<tr><td>3</td><td>Select set date and time</td></tr>
<tr><td>4</td><td>Enter the correct date and time using steps below</td></tr>
<tr><td></td><td>
<table>
<tr><th>To…</th><th>Press…</th></tr>
<tr><td>Increase the value of selected digit</td><td>□↑□</td></tr>
<tr><td>Decrease the value of selected digit</td><td><↓></td></tr>
<tr><td>Select the next digit or field</td><td>ENTER</td></tr>
</table>
</td></tr>
<tr><td>5</td><td>Press ENTER when the correct information has been entered.
<table>
<tr><th>To….</th><th>Select …</th></tr>
<tr><td>Update the selected date and time.</td><td>Set date/time</td></tr>
<tr><td>Return date/time screen without saving changes</td><td>Cancel</td></tr>
</table>
</td></tr>
</table>

3.3.4 Setting the Alarm

An audible alarm can be set to alert the worker of approaching threshold limits. The concentration level must be set to the defined agency standard for the particulate type being sampled

. Follow the steps in the table below to set the alarm level

Table 3.3 Setting the Alarm

<table>
<tr><td>Steps</td><td>Action</td></tr>
<tr><td>1</td><td>Select special function from the main menu</td></tr>
<tr><td>2</td><td>Select set alarm</td></tr>
<tr><td>3</td><td>Enter the appropriate concentration level using the table below</td></tr>
<tr><td></td><td><table>
<tr><th>To ….</th><th>Press …</th></tr>
<tr><td>Increase the value of the selected digit</td><td><↑></td></tr>
<tr><td>Decrease the value of the selected digit</td><td><↓></td></tr>
<tr><td>Select the next digit</td><td>ENTER</td></tr>
</table></td></tr>
<tr><td>4</td><td>Press ENTER after the last digit is entered</td></tr>
</table>

3.3.5 Clearing the Memory

The memory of the EPAM-5000 can be cleared at any time. Follow the steps in the table below to clear the memory of the EPAM-5000.

Table 3.4 Clearing the Memory

Steps	Action
1	Select **special function** from the main menu.
2	Select **system options.**
3	Select **erase memory.**
4	Select **yes** to clear memory.

3.4. Operating the EPAM-5000

This chapter describes and diagrams operation procedures of the EPAM-5000.

3.4.1. Selecting the Particle Size

The inlet system of the EPAM-5000 can be configured to sample TSP, PM 1.0, 2.5, 10.0 μm dust particulates. The following pages detail the selection process for each of these particle types. Impactor Sleeve holds one optional accessory.

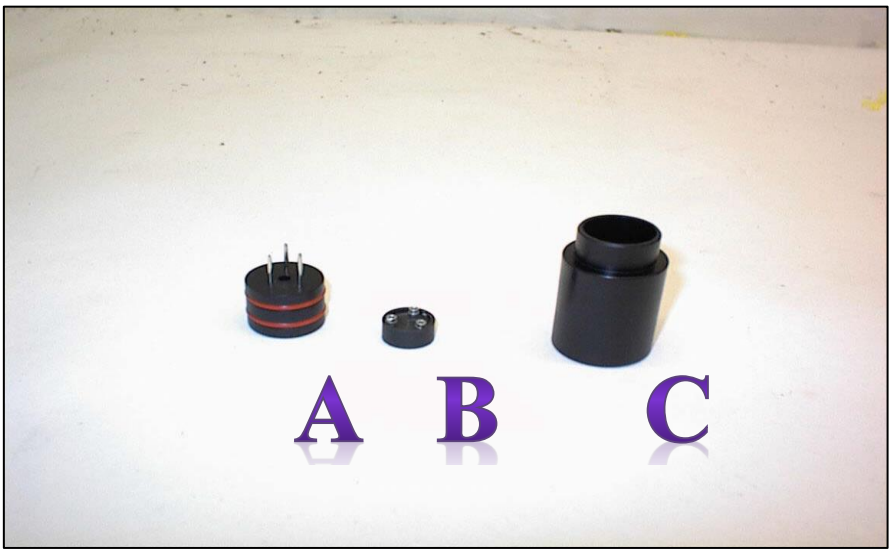

Fig.3.9.0 Picture: A) Impactor Jet, B) Impaction cup, and C) Impactor Sleeve. For TSP sampling use impactor sleeve without impactor. One Size Selective Inlet is provided with EPAM-5000. Impactors are engraved on bottom of jet

3.4.2. $PM_{2.5}$.

First of all 2.5-μm size select from the setting of the EPAM-5000

Now follow the steps in the table below to select $PM_{2.5}$ particulates.

Table3.5 $PM_{2.5}$

Steps	Actions
1	Select **special functions** from the main menu.
2	Select **system option.**
3	Select**extended option**.
4	Select **size select.**
5	Select **$PM_{2.5}$.**

	Result: the mainmenu displayed.
6	Insert the inlet head into the sensor head of the EPAM-5000.
7	Attach the filter cassette holder to the sensor of the EPAM-5000.

3.4.3. Process of reviewing stored Data.

The EPAM-5000 provides extensive capabilities for reviewing internally stored data and statistics on the LCD or downloading to a PC using Dust Comm Pro Software

(a)The following information can be displayed on the LCD.

Table 3.6 Process of reviewing stored Data

Display	Disruption tag.
Date	Date of sampling.
Start	Time samplings began.
Stop	Time sampling was terminated.
Time	Time of occurrence of reported statics.
Maximum sample	Highest concentration of dust particles.
Minimum sample	Lowest concentration of dust particles.
T.W.A	Time weighted average concentration of dust particles.
Elapsed	Elapsed time of weighted average.
S.T.E.L	Shortterm exposure limit.

(b) Viewing Data on the LCD.

Follow the steps in the table below to review stored information and statistics.

Table 3.7 Viewing Data on the LCD

Steps	Action	
1	Select review data.	
2	Select statistics.	
3	Determine your next steps using the table below.	
	If…	**Then the…**
	Memory holds data points in the other locations.	Thes canning memory screens display.
	Memory has been cleared of	No data recorded

<table>
<tr><td></td><td>all data pints.</td><td></td></tr>
<tr><td>4</td><td colspan="2">Select the location using the table below</td></tr>
<tr><td></td><td colspan="2"><table><tr><th>To review…</th><th>Select ….</th></tr><tr><td>A different location.</td><td>New tag XXX and go to step 7.</td></tr></table></td></tr>
<tr><td>5</td><td colspan="2">Enter the desired location andselect screen using the table below.</td></tr>
<tr><td></td><td colspan="2"><table><tr><th>To …</th><th>Press …</th></tr><tr><td>Increase the value of selected digit.</td><td><↑></td></tr><tr><td>Decrease the value of selected digit.</td><td><↓></td></tr><tr><td>Select the next digit or field.</td><td>ENTER.</td></tr></table></td></tr>
<tr><td>6</td><td colspan="2">Press ENTER when desired location code has been entered.
<u>Result:</u> The location is shown on the display. If the location is being reviewed for the first time scrolling dots will appear indicating the microprocessor is computing data.</td></tr>
<tr><td>7</td><td colspan="2">The first of five statistics screen appears when data is computed. Scroll through the statistics screen table below.</td></tr>
<tr><td></td><td colspan="2"><table><tr><th>Press ….</th><th>To scroll…</th></tr><tr><td><↓></td><td>Forward through the statistics screen.</td></tr><tr><td><↑></td><td>Backward through</td></tr></table></td></tr>
</table>

3.4.4. Filter medium selection.

In general, the use of selected filter medium depends on purpose of the test. Selection of a filtration substrate for time-integrated PM_{10} and $PM_{2.5}$ monitoring was made with some knowledge of the expected characteristics and a pre-determined analytical protocol.

Several characteristics are important in the selection of filter media. They are

- **Particle sampling efficiency**. Filters should remove more than 99% of SPM drawn through them, regardless of particle size or flow rates.
- **Mechanical stability**. Filters should be strongenough to minimize leaks during sampling and wear during handling.

- **Chemical stability**. Filters should not chemically react with thetrapped SPM.
- **Temperature stability**. Filters should retain their porosity and structure during sampling.

3.4.5. Visual Filter Inspection

All filters were visually inspected for defects before use, and defective filters were rejected if found. Specific defects that were looked for:

- **Pinhole**: A small hole appearing as a distinct and obviousbright point of light when examined over a light table or screen.
- **Loose material:** Any extra loose material or dirt particles on filter were brushed off beforethe filter is weighed.
- **Discoloration:** Any obvious visible discoloration that might be evidence of a contaminant.
- **Filter non uniformity:** Any obvious visible non uniformity in the appearance of the filter when viewed over a light that might indicate gradations in porosity across the face of the filter.Each filter was visually inspected in front of an area light and any specific defects listed above were observed. Each filter was coded on the non-exposable area before tare weighing.

Chapter 4

RESUTS AND DISCUSSIONS

This chapter describe the important results and variation of the experimental data which have found during the entire experiment period. So using all result a relation has been tried to establish among them i.e. variation of concentration of $PM_{2.5}$ during post monsoon, winter and summer with the temperature. The variation in temperature and RH would have their effect on $_{PM2.5}$ concentrations. Therefore the variation in ambient RH and corresponding changes in temperature from October to December, 2017 and from January to May 2018 on four hour mean data are plotted. From October to November, 2017 the ambient temperature was less variable, while RH has registered higher values. Later, temperature gradually decreased at the end of 2017, while RH increased from October to November 2017.

The post-monsoon data of 2017,the winter data from December 2017 to January 2018 and The summer data of 2018 were analysed. The variability in $PM_{2.5}$ concentrations was computed and presented in the form of graph for the winter, summer and post monsoon respectively. The $PM_{2.5}$ concentrations decrease in summer and attain its maximum in the post monsoon (October to November 2017).

Seasonally the concentration is highest in post-monsoon for $PM_{2.5}$ due to prevailing winds, lower RH and local Effect of Diwali festival and due to crop burning near the surrounding states of Delhi NCR. In India, during Diwali, crackers on large scale especially in urban areas, add significant amount of anthropogenic pollutants into local environments.

During 15 to 20 October, 2017 (Diwali day was on 19th October), the occurrence of high $PM_{2.5}$, and PM_{10} concentration between 100 μg/ m^3 and 700 μg/ m^3 in the daily running mean and between 100 μg/ m^3 and 200 μg/m^3 in the seasonal running mean during the post-monsoon, 2017, which were attributed to bursting of crackers on Deepawali days. Also, low winds, mixing height up to300 m, low temperature up to 20 °C and high RH contributed to these PM levels. RSPM levels over Delhi during Deepawali, 2017 was reported about 610– 1294 μg /m^3 by the central pollution control board (http://www.cpcb.nic.in/Air- Quality-Delhi.php), which are

comparable with $PM_{2.5}$, and PM10 concentrations during post-monsoon season of 2017).

The average concentration of $PM_{2.5}$ was observed 58.25 µg/ m^3, 272.66 µg/ m^3 and246.66 µg/ m^3 in summer, post-monsoon and winter respectively.

The average concentration of $PM_{2.5}$ during Diwali day of 2015, 2016 and 2017 were observed 430 µg/ m^3, 1237 µg/ m^3 and 657 µg/ $m^{3.}$

It has been seen that the concentration of particulate matters are drastically increased in Delhi during October –November every year due to the practice of crop residue burning in the surrounding states of NCR.

4.1. Analysis of $PM_{2.5}$ in Post monsoon (October-November 2017)

The analysis of $PM_{2.5}$ during the post monsoon season is carried out in the form of bar chart diagram on alternate day basis from 2 October to 15 November 2017.

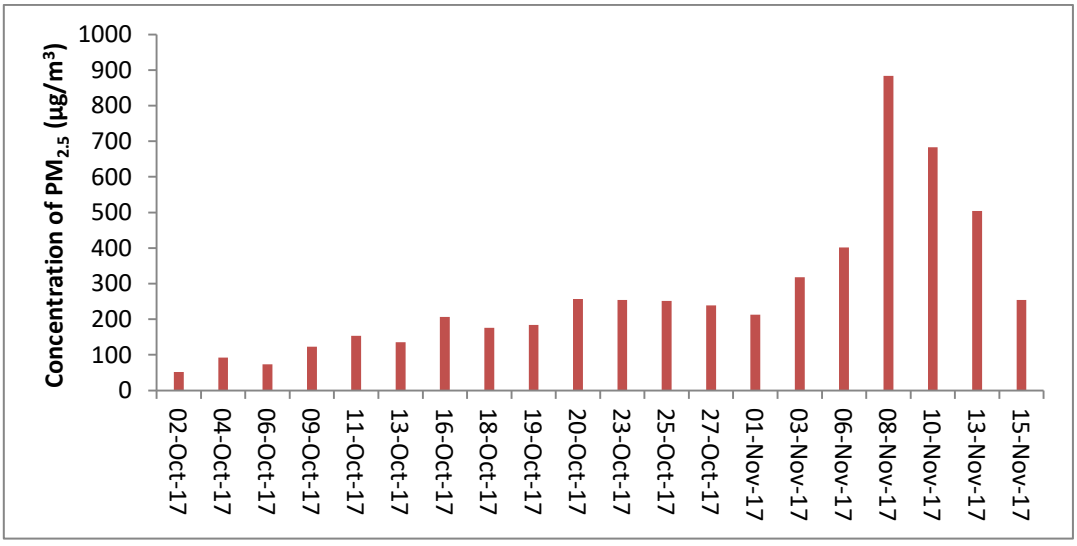

Fig 4.1 Bar chart showing Concentration of $PM_{2.5}$ (µg/m^3) in post monsoon

The above figure shows the variation of $PM_{2.5}$ concentration from 2 October,2017 to 15 November 2017. During this period the variation in concentration of $PM_{2.5}$ was found maximum in the interval of 16 October to 25 October and 3 November to 17 November. The reason of variation in concentration of $PM_{2.5}$ during 16 October to 25 October is bursting of crackers on the ocasion of Diwali and for the interval 3 November to 17 November is practice of crop burning residue in the surrounding state of Delhi. In the post monsoon season Experiment was carried out in the month of October and November 2017. Data were recorded with the help of EPAM5000

instrument alternate day between 12pm to 4pm. It has been found that minimum concentration of $PM_{2.5}$ was observed 51.56 μg/m^3 and maximum was 883.34 μg/m^3. During this period visibility was reduced too much due to which all transportation system is disturbed.

It has very harmful effects on the human health and people suffering from various health problem such as breathing problem, eye irritation, aggravating asthma and lung function badly affected.

4.2 Analysis of $PM_{2.5}$ in Winter (December 2017 to January 2018)

The analysis of $PM_{2.5}$ for the winter seasons is carried out in the month of December 2017 to January 2018 on the alternate day basis which is represented in the form of bar chart diagram

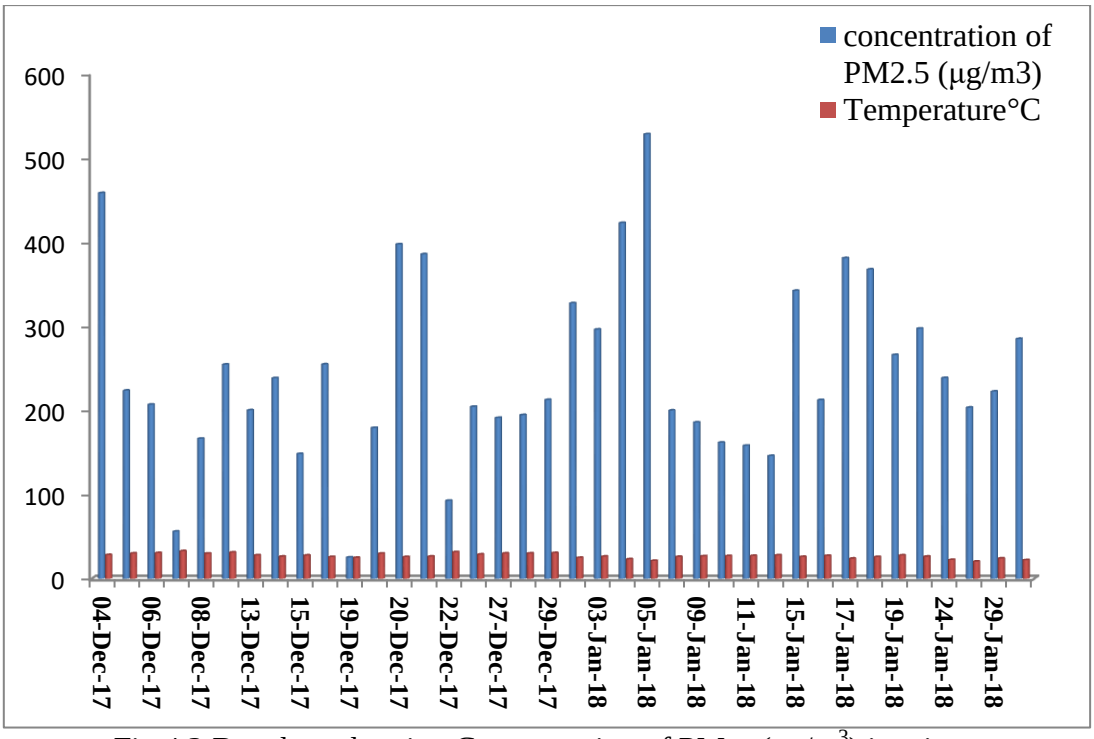

Fig 4.2 Bar chart showing Concentration of $PM_{2.5}$ (μg/m^3) in winter

The above fig.4.2 shows the variation of $PM_{2.5}$ concentration and temperature variation for the winter season (4 December 2017 to 30 January 2018). The observed average concentration of $PM_{2.5}$ in winter is 246.67 μg/m^3 against the acceptable limit of 60(μg/m^3). It has been found that the concentration of $PM_{2.5}$ was maximum observed 528.88(μg/m^3) and minimum 25.38 μg/m^3, reason behind high

concentration is low mixing height and inversion condition formed during winter. Due to inversion condition formed in the topographic sphere the pollutant during winter is not able to rise at higher level and dispersion of pollutant is not occurred smoothly in the atmosphere. The main source of $PM_{2.5}$ in the winter season is secondary particles i.e. Oxides of nitrogen, Oxides of sulphur ammonia etc. Combustible substances are also responsible for $PM_{2.5}$ in winter, the burning of MSW produces higher $PM_{2.5}$ in winter than in summer. It has been observed that in winter the atmosphere looks very hazy and smoky which formed very unhealthy air. The consistent and major contributors appear to be secondary particles and combustion related emission with main contributors of burning of MSW.

Over all it has been concluded that combustion sources, vehicles, biomass burning and MSW burning are the consistent sources in winter and these things require a special strategy to control the sources.

4.3 Concentration of $PM_{2.5}$ in summer (2 April to 30 May 2018)

The description of experimental data of the concentration of $PM_{2.5}$ for the summer season is represented in line diagram as shown in the figure 4.3.

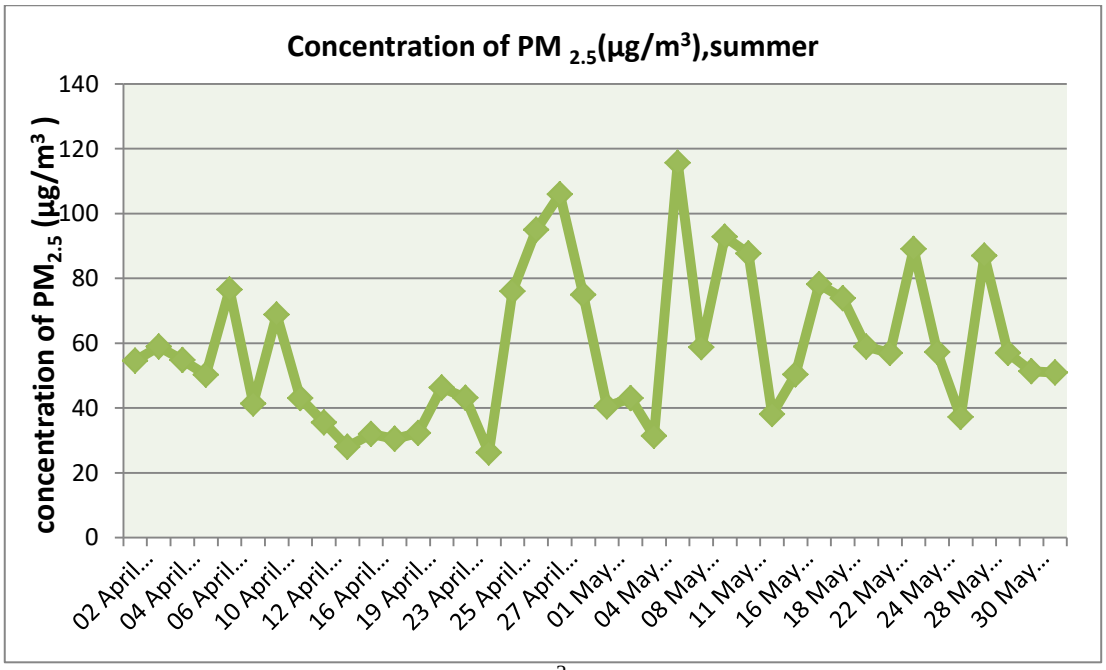

Fig 4.3 Variation of $PM_{2.5}$ ($\mu g/m^3$) & temperature(°C) in summer

The above fig.4.3 represents the variation of $PM_{2.5}$ in summer. The data are recorded from 2 April to 30 May 2018 an alternate day basis from 12pm to 4 pm, and it has

been found that overall average concentration of $PM_{2.5}$ in summer season is around 58.25 which is nearly equal to acceptable limit (60 $\mu g/m^3$). The maximum concentration recorded during summer is 115.62 $\mu g/m^3$ and minimum concentration recorded is 26.25 $\mu g/m^3$. In summer the road dust and airborne fly ash is the main source of $PM_{2.5}$, secondary particles also account for the $PM_{2.5}$ in summer. The burning of MSW waste is also responsible for $PM_{2.5}$ in summer. In summer air quality can not be improved unless we find effective control solution for soil and road dust, fly ash re-suspension, MSW burning etc.

4.4 Analysis of average concentration of $PM_{2.5}$

After the analysis of $PM_{2.5}$ in post-monsoon, summer and winter the average concentration of $PM_{2.5}$ was calculated and shown in the graphical format as shown in the figure.

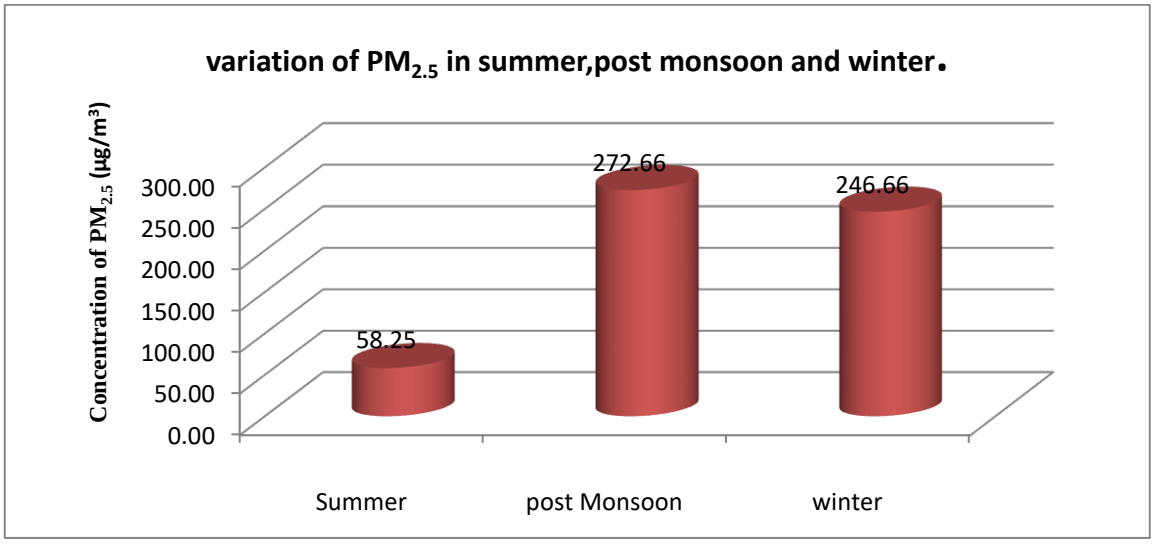

Fig 4.4 Average concentration of $PM_{2.5}$ ($\mu g/m^3$) in summer, post monsoon and winter

In the above fig 4.4 the average concentration of $PM_{2.5}$ of summer, post monsoon and winter has been represented in the graphical form. The maximum concentration was found in post monsoon i.e. in the month of October-November 2017 and minimum in summer. After all discussion it can be said that the concentration of $PM_{2.5}$ is found minimum in summer in compression of post monsoon and winter. The percentage decrease in concentration of $PM_{2.5}$ in summer with respect to standard value of $PM_{2.5}$ is 2.91% and increase in concentration of $PM_{2.5}$ in post monsoon and

winter are 354.44%, 311.10% respectively with respect to standard value(60 μg/m^3) of $PM_{2.5}$. So, summer create healthy atmosphere in respect of $PM_{2.5}$ for all human health as well as animal and plants.

4.5 Concentration of PM $_{2.5}$ during pre-Diwali and Diwali day

In the fig.4.5 concentration of $PM_{2.5}$ of pre- Diwali day for the year 2015,2016 and 2017 has been shown in the following figure.

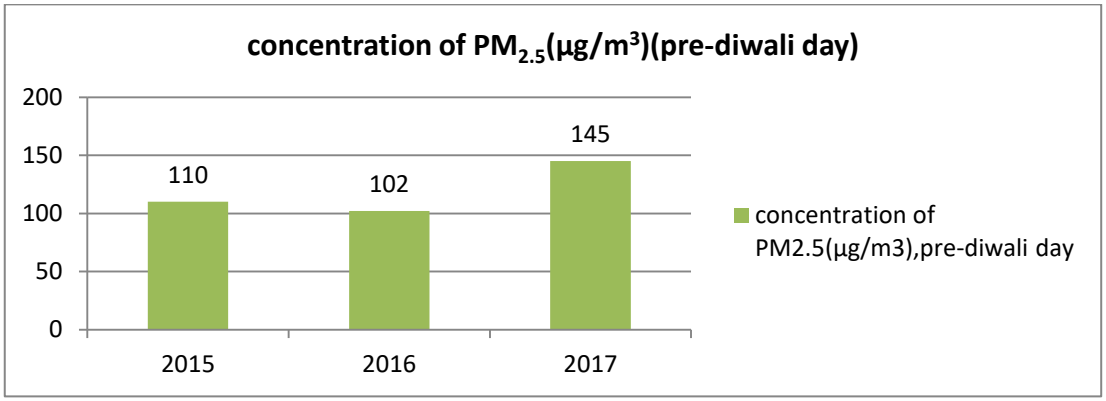

Fig 4.5 Concentration of $PM_{2.5}$ (pre-Diwali day)

The above graph represents that the concentration of $PM_{2.5}$ in 2017 at pre- Diwali day was more than 2015 and 2016 due the formation of inversion condition near the ground level and air pollutants are not able to attain the mixing height.

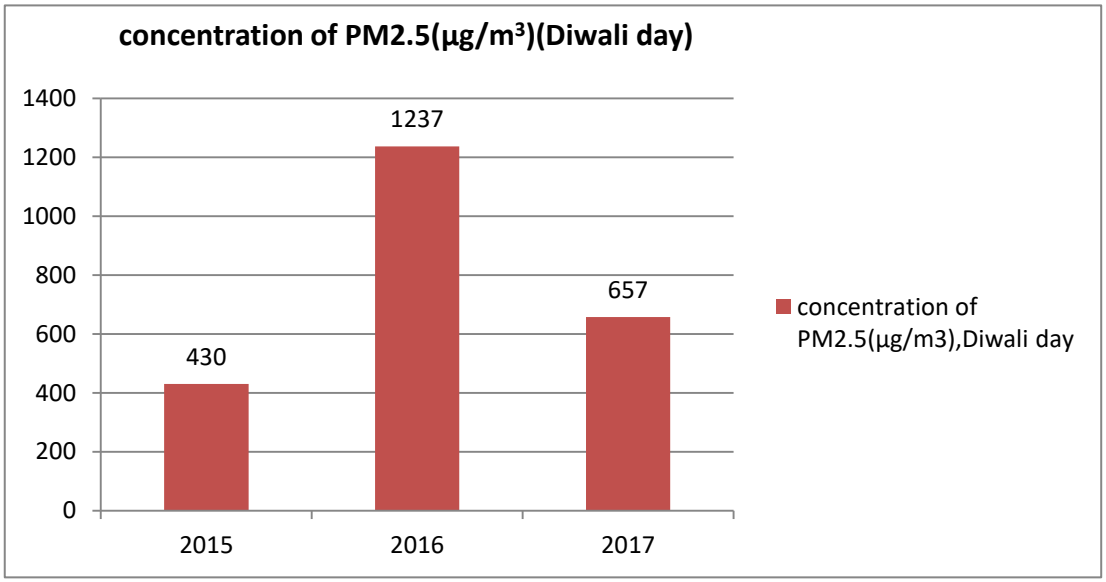

Fig 4.6 Concentration of $PM_{2.5}$ (Diwali day)

The figure 4.6 shows the variation of $PM_{2.5}$ of 2015, 2016 and 2017. The avg. concentration found at Diwali day in 2015, 2016 and 2017 were observed 430 $\mu g/m^3$, 1237 $\mu g/m^3$ and 657 $\mu g/m^3$. The concentration of $PM_{2.5}$ in 2016 was much higher in compression of concentration of $PM_{2.5}$ in 2015 and 2017.

The main reason behind this was the burning of crop residue and bursting of crackers on the occasion of Diwali. The concentration of $PM_{2.5}$ was less in 2017 compression of concentration of $PM_{2.5}$ in 2016, because banning of fire crackers on the occasion of Diwali in Delhi, but since in the neighbour states of Delhi practices fire crackers on the occasion of Diwali whose effects contributed in $PM_{2.5}$ concentration.

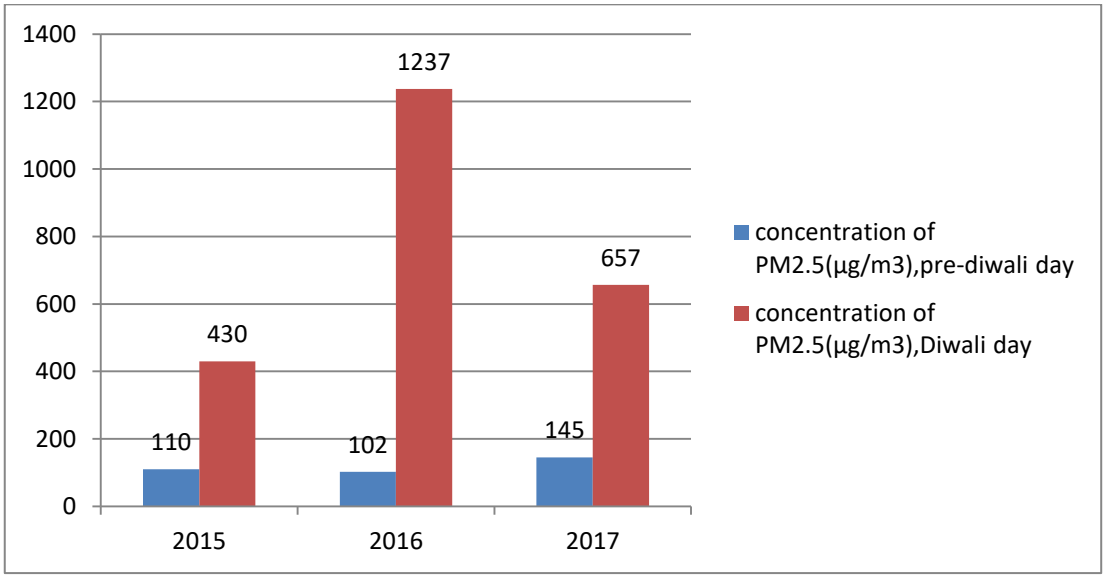

Fig 4.7 Variation of concentration of $PM_{2.5}$ during pre-Diwali day & post-Diwali day

In this section variation of concentration of $PM_{2.5}$ during pre-Diwali day and Diwali of previous three year has been represented and it was found that the maximum concentration of $PM_{2.5}$ in 2016 which was 1237 $\mu g/m^3$. The concentration of $PM_{2.5}$ in 2017 was found less than the concentration of $PM_{2.5}$ in 2016 because the ban of fire crackers in Delhi. But in spite of banning the fire crackers in Delhi the concentration of $PM_{2.5}$ not decreases too much due to the effect of crop residual burning in the surrounding states of Delhi.

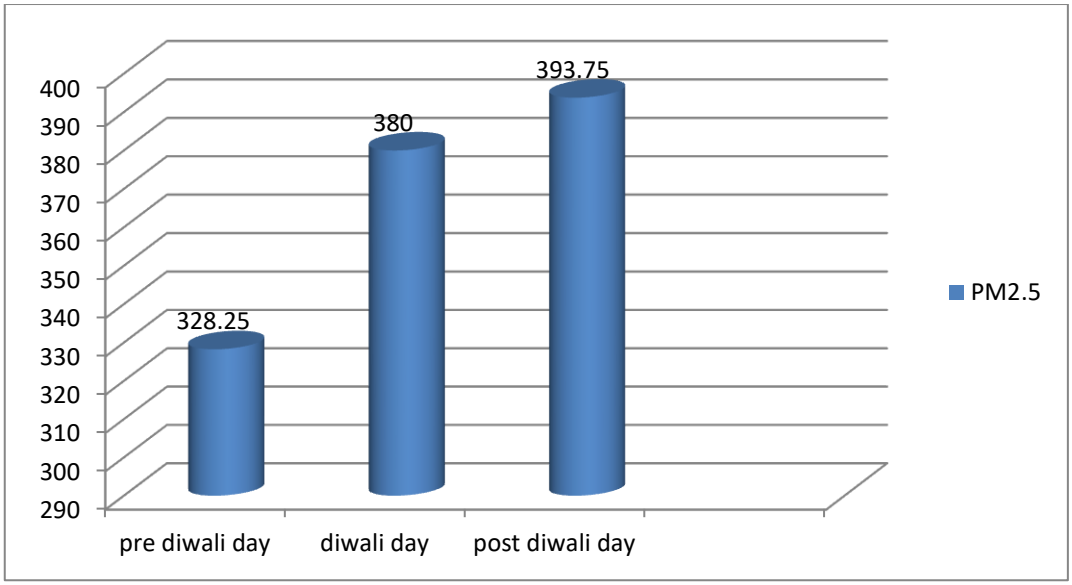

Fig 4.8 Concentration of $PM_{2.5}$ during pre-Diwali, Diwali and post Diwali day, 2017.

(Source: CPCB)

Fig 4.8 shows the concentration of $PM_{2.5}$ during pre- Diwali, Diwali and post Diwali day in 2017. The above data varies from my experimental data because it depends on varies parameter such as exact location of instrument, wind speed, wind direction and altitude at which instrument is established.

4.6 Limitation of my study

Duration of Battery is only 6 hour, so data of more than 6 hour is not able to record.

Chapter 5

CONCLUSION

After over all discussion it has been concluded the following conclusion:

(i) Assessments of $PM_{2.5}$ particles concentration is presented in this Dissertation on four hour daily basis in DTU campus. Seasonally concentration of $PM_{2.5}$ is maximum in post monsoon 272.66 μg /m^3 followed by winter 246.66 μg/ m^3 due to prevailing winds, lower boundary layer height and RH and minimum concentration was found in summer 58.25 μg/ m^3.

(ii) The concentration of $PM_{2.5}$ was found minimum in summer due to high mixing height and more dilution in the atmosphere of pollutant at greater height.

(iii) Over all maximum concentration of $PM_{2.5}$ was observed during Diwali festival (657 μg/ m^3) due firecrackers bursting and practice of crop residue burning.

(iv) Bursting of fire-crackers during Diwali, quick gravitational settling of coarse particles as against longer residence time of fine particles and lower boundary layer height are responsible for high concentration of $PM_{2.5}$.

(v)However, increased levels of smaller particles ($PM_{2.5}$) are the main concern to human being because of their longer atmospheric residence time, higher surface to volume ratio, more pronounced impact on health, visibility, direct, indirect and semi-direct climatic effects and impact on ecosystem, structures, etc.

(vi)The seasonal variability of $PM_{2.5}$ levels and their proportion in each season presented in this thesis may be useful in policy decision making process to improve the air quality of Delhi.

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Annexure (A)

Concentration of $PM_{2.5}$ in post monsoon

Date		Concentration of PM2.5(µg/m3)
02-Oct-17		51.56
04-Oct-17		92.06
06-Oct-17		73.62
09-Oct-17		122.52
11-Oct-17		153.05
13-Oct-17		135.19
16-Oct-17		206.56
18-Oct-17		176.32
19-Oct-17		183.64
20-Oct-17		256.63
23-Oct-17		254.03
25-Oct-17		251.6
27-Oct-17		239.06
01-Nov-17		212.81
03-Nov-17		318.31
06-Nov-17		401.19
08-Nov-17		883.34
10-Nov-17		683.15
13-Nov-17		504.2
15-Nov-17		254.38

Annexure (B)

Variation of Concentration of $PM_{2.5}$ and temperature in winter

Date	concentration of PM2.5(µg/m3)	Temperature°c
04-Dec-17	458.88	28.35
05-Dec-17	224.97	30.26
06-Dec-17	208.36	30.75
07-Dec-17	56.44	33
08-Dec-17	167.57	30
11-Dec-17	255.76	31.48
13-Dec-17	201.57	28
14-Dec-17	239.67	26.38
15-Dec-17	149.4	27.81
18-Dec-17	255.96	26
19-Dec-17	25.38	25
20-Dec-17	180.56	30
20-Dec-17	398.12	26
21-Dec-17	386.36	26.54
22-Dec-17	93.31	31.8
26-Dec-17	205.81	29
27-Dec-17	192.56	30.23
28-Dec-17	195.94	30.25
29-Dec-17	213.98	30.79
02-Jan-18	328.35	25
03-Jan-18	297.25	26.48
04-Jan-18	423.43	23.24
05-Jan-18	528.5	21.36
08-Jan-18	201.36	26.23
09-Jan-18	187.07	26.88
10-Jan-18	162.94	27.12
11-Jan-18	159.25	27.36
12-Jan-18	146.97	27.98
15-Jan-18	343.12	26.18
16-Jan-18	213.75	27.34
17-Jan-18	381.81	24.05
18-Jan-18	368.44	26
19-Jan-18	267.14	27.88
23-Jan-18	298.31	26.42
24-Jan-18	239.88	22.46
25-Jan-18	204.75	20.53
29-Jan-18	223.89	24.22
30-Jan-18	286.12	22.14

Annexure(C)

Variation of Concentration of $PM_{2.5}$ and temperature in summer

Date	Concentration of PM2.5($\mu g/m^3$)	Temperature(°C)
02 April 2018	54.55	34.43
03 April 2018	58.92	35.07
04 April 2018	54.81	35.61
05 April 2018	50.23	36
06 April 2018	76.5	36.18
09 April 2018	41.32	30.01
10 April 2018	68.81	33.24
11 April 2018	43	31.67
12 April 2018	35.56	34.24
13 April 2018	28	36
16 April 2018	32	35.61
17 April 2018	30.5	36.41
19 April 2018	32.25	36.16
20 April 2018	46.29	36.34
23 April 2018	43.09	36.26
24 April 2018	26.25	36.73
25 April 2018	76	36.94
26 April 2018	95	36.09
27 April 2018	106	37.12
28 April 2018	74.96	36
01 May 2018	40.5	33.12
03 May 2018	43	34.39
04 May 2018	31.39	33.97
07 May 2018	115.62	34.68
08 May 2018	58.75	36.46
10 May 2018	92.81	34.89
11 May 2018	87.71	33.97
14 May 2018	38.12	37.16
16 May 2018	50.38	38.09
17 May 2018	78.19	37.98
18 May 2018	73.81	37.67

21 May 2018	58.89	41.79
22 May 2018	56.93	45.37
23 May 2018	89.06	42.78
24 May 2018	57.25	25.2
25 May 2018	37.25	27.98
28 May 2018	87.01	31.29
29 May 2018	56.98	28.12
30 May 2018	51.31	38.22
31 May 2018	50.95	38.52

Annexure (D)

Average seasonal Concentration of $PM_{2.5}$ ($\mu g/m^3$) and Temperature (°C)

	Concentration of $PM_{2.5}$ ($\mu g/m^3$)	Temperature(°C)
Post monsoon	272.661	31.20
winter	246.66	27.12
summer	58.25	35.44

Annexure (E)

Concentration of $PM_{2.5}$ ($\mu g/m^3$) in Pre- Diwali Day and Post-Diwali Day

Year	Concentration of $PM_{2.5}$ ($\mu g/m^3$) Pre-Diwali Day	Concentration of $PM_{2.5}$ ($\mu g/m^3$) Post-Diwali Day
2015	110	430
2016	102	1237
2017	145	657