

**A STUDY OF SIZE FRACTIONATED  
AEROSOLS IN THE VICINITY OF BADARPUR  
THERMAL POWER STATION (BTPS) IN DELHI**

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Submitted by

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## CERTIFICATE

The research work embodied in this dissertation entitled "A STUDY OF SIZE FRACTIONATED AEROSOLS IN THE VICINITY OF BADARPUR THERMAL POWER STATION (BTPS), IN DELHI" is done by Bhawna Sharma under the supervision of Dr. V. K. Jain in partial fulfillment of the requirements for the degree of Master of Philosophy. The work is original and has not been submitted in part or full for any other degree or diploma to any university.



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# CHAPTER I

## INTRODUCTION

Ambient air acts as an atmospheric sink, where all emissions are released. Many such emissions are in such small quantities that they get immediately dissipated and absorbed but continuous release of these pollutants builds up in the air, which may have impact on human health and climate. Air pollution encompasses a diverse array of natural and anthropogenic emissions, including gaseous constituents, volatile chemicals, aerosols (particulate) and their atmospheric reaction products.

Increasing pollution processes are responsible of the worsening of air quality particularly in urban and metropolitan areas. The atmospheric particulates of industrialized cities have become a mixture of potentially toxic substances with concentrations harmful to public health. Trace metal and elements are part of these pollutants and their monitoring becomes very important in assessing air quality. The measurement of their total concentration in the air as well as their distribution in different aerosol particle sizes is necessary to evaluate the atmospheric pollution risk in terms of both: maximum present levels and long term exposure. The knowledge of the size distribution of city air and its respirable fraction can give important information that is necessary not only to evaluate actual pollution level but also developing pollution abatement measures. The majority of metallic air pollution is associated with solid particulate material (*Harrison, 1986a*). Generally most of the metals are associated with particles with diameters in the 0.6-10  $\mu\text{m}$  range (*Davidson, 1980, Nriagu 1980*).



## **1.1 Aerosols**

The atmospheric aerosols are defined as an assembly of liquids and solids particles suspended in gaseous medium, usually air. (*Vincent, 1989; Baron and Willeke; 1993*). The most commonly determined parameters pertaining to aerosols are mass concentration i.e. the mass of particulate matter contained in a unit volume of air, mass or number size distribution, and its chemical composition (*Vincent, 1989*).

Atmospheric aerosol is a mixture of naturally occurring substances, materials introduced into the atmosphere by human activities and products of gas-to-particle conversion processes in the atmosphere. Therefore, if we plan to control aerosol pollution or estimate its effects on earth's ecological system we must determine all the above stated parameters.

## **1.2 Role of Aerosols in the Atmosphere**

Atmospheric aerosol particles, ubiquitous in the lower atmosphere play an important role in global climate. These particles, consisting of complex inorganic and organic compounds, affect the radiation budget, both directly by scattering and absorbing incoming solar radiations and outgoing terrestrial radiations and indirectly, through their ability to modify cloud microphysics and albedo (*Charlson et al, 1991*). Generally speaking aerosols in the stratosphere may cause a cooling effect on the air near the ground while in the troposphere they may lead to warming of the layer of the air where they exist. In addition, the scattering capability of atmospheric aerosols has implications for various human activities, limiting visibility and the transmission of other electromagnetic radiations. Further atmospheric aerosol particles play an important role

in strongly influencing the life times of various trace gas species, such as SO<sub>2</sub> and ammonia by providing rapid removal mechanism (*Chameides and Stelson, 1992*).

Moreover, aerosols play a carrier's role in atmosphere i.e. they deliver chemical compounds from certain place to other places. In addition, aerosols have strong surface absorption, which can expedite the absorption of SO<sub>2</sub> and can oxidize it to become sulphate with time. Through photo-oxidation eventually SO<sub>2</sub> in the atmosphere will probably be oxidized into H<sub>2</sub>SO<sub>4</sub>, and may form acid deposits.

Since the effects of the particles depend on their sizes and chemical composition, determination of mass balance as a function of the size is of particular importance. The chemical mass balance of coarse and fine particles has been studied in several works as compiled by *Heintzenberg in (1989)*.

### 1.3 Sources of Aerosols

Aerosols can originate from a variety of sources, like human activities, photochemical processes, gas to particle conversions, eolic erosion, oceans etc. Therefore, there is a considerable variation in the composition and physical properties of the particles, depending on the sources, their geographical locations and meteorological conditions. *Seinfeld & Pandis (1998)* have given a complete review about the physico-chemical processes involving the aerosols. Complex size distribution of air borne particles in ambient systems results from a multiplicity of sources generating particles of different compositions, usually at a variable rate, and also from post formation processes that alter particle's physical and chemical characteristics.

#### 1.4 Health Impact of Aerosols

*Dockery and Pope (1994)* reported that for each  $10\mu\text{g}/\text{m}^3$  increase in concentration of particulate matter ( $<10\mu\text{m}$  in diameter) there is an estimate of increase in mortality of 0.6-1.6%. The health impact of finest particle is greater because it can be inhaled deep into the unciliated and alveolar section of the lungs.

Concern over the adverse human health impacts of aerosols have lead a number of national and international agencies to propose challenging air quality standards. The standard setting process has been based upon an analysis of the results of epidemiological studies which have linked air borne concentrations of particulate matter, in most instances measured as PM<sub>10</sub>, with a variety of health outcomes, including both morbidity and mortality. The studies indicate that exposure to air borne particulate matter is associated with an increased incidence in both respiratory and cardiac diseases and the similarity of exposure-response coefficients from cities in different parts of the world indicate that the chemical composition of the particles is unlikely to be a major drive of these effects on health (*Harrison and Yin 2000*). TSP mass fractions do not seem to be the best parameter for the explanations of respiratory diseases; it can, however, be a good indicator if the particle size distribution does not vary greatly between regions. Countries around the world have set air quality standards based upon PM<sub>10</sub> (e.g. EPAQS, 1995) or both PM<sub>10</sub> and PM<sub>2.5</sub> as metrics of mass concentration.

In epidemiological studies, respiratory health related effects were found for TSP and distinct finer fractions (e.g. PM<sub>10</sub>, PM<sub>2.5</sub>). Respiratory health effects are biologically expected to be associated with particles smaller than  $10\mu\text{m}$  passing the nose and entering lung alveoli. In addition to particle size the number of inhaled particles can be of great

importance change of the median particle diameter from 1 to 0.1 $\mu$ m increases the number of particles by more than a factor of a thousand for constant mass fraction. This can cause problem in the macrophage clearing mechanism. Macrophage clearing is more efficient for a smaller number of larger particles than for very high numbers of fine particles (*Kreylig 1994*).

One of the first studies (World Bank, 1995) correlating health with air pollution in India stated that small particles like PM10 and gases like SO<sub>2</sub> are responsible for 95% of health damage (*Ware et al, 1986; Schwartz, 1994; Gamble & Lewis, 1995 and Ostro, 1995*) A recent study reveals that Delhi's Air Pollution is responsible for over 40% of the emergency hospital admissions with respiratory and heart problems.

The World Health Organization (WHO) estimates that as many as 1.4 billion urban residents in the world breathe air exceeding the WHO air quality guidelines (*World Resource Institute 2000*)

### **1.5 Emissions from Thermal Power Plants**

Coal on combustion in power stations gives rise to emissions of primary (direct emissions) and secondary (gas to particle conversions) particulate pollutants. Since the emissions of pollutants depend on coal quality and combustion technology, and given that transport, transformation and deposition of contaminants depend on regional climate conditions, specific studies for the power stations need to be carried out to evaluate their environmental impact. Although particulate controls in power stations have high efficiency rates (nearly 99.9 for electrostatic precipitators), considerable amounts of fly ash are discharged in to the environment due to the high coal consumption.

A 1000 MW power station with the normal consumption of 12000 tonnes of sub-bituminous coal per day has a mean combustion waste production of about 2,400 tonnes per day. If the 99.9% efficiency rate is assumed for the electrostatic precipitators, almost 900t of fly ash per year are transferred to the atmosphere. These primary aluminosilicate particles may have diameter  $>20\mu\text{m}$  (*Querol et al; 1996*)

Since the gas to particle conversion processes, controlling the secondary particulate emissions is very much dependent on the meteorological conditions (insolation and humidity are major parameters controlling the sulphate and nitrate formation), important seasonal variations in the levels of secondary particulate pollutants must be expected (*Monn, 1995*).

Many trace elements can be enriched in coal due to the very strict geochemical environment produced during peatification and coalification. Power generation from coal-fired stations constitutes a potential mobilization mechanism for these elements. Recent studies demonstrated that the gaseous emission of many trace elements from coal combustion is reduced due to the post-combustion condensation and sorption processes occurring in the particulate control devices. However important volumes of particulates associated potentially toxic elements are emitted from power stations due to the large coal combustion.

Transformations undergone by gaseous plumes lead to the production of large volumes of secondary aerosols (*Franzle, 1993 and Hidy, 1994*) through different physical and chemical processes such as homogenous and /or heterogeneous nucleation.

The reasons why certain trace elements are most concentrated in the fly ash particles emitted from coal fired power plant are not clear. One attractive explanation is that the element (or one of its compounds) volatilizes in the high-temperature coal

combustion zone and then either recondenses preferentially or is absorbed preferentially on to the large available surface area per unit mass provided by the small particles (D.F.S. Natusch et al., 1974).

The main emissions from coal combustion at thermal power plants are carbon dioxide (CO<sub>2</sub>), nitrogen oxides (NO<sub>x</sub>), sulfur oxides (SO<sub>x</sub>), chlorofluorocarbons (CFCs), and air-borne inorganic particles such as fly ash, soot, and other trace gas species. Carbon dioxide, methane, and chlorofluorocarbons are greenhouse gases. These emissions are considered to be responsible for heating up the atmosphere, producing a harmful global environment. Oxides of nitrogen and sulfur play an important role in atmospheric chemistry and are largely responsible for atmospheric acidity. Particulates and black carbon (soot) are of concern, in addition to possible lung tissue irritation resulting from inhalation of soot particles and various organic chemicals that are known carcinogens.

## **1.6 Metals in Aerosols**

Urban populations are exposed to metals in suspended particles and these are often well above natural background levels owing to anthropogenic processes. The elevated metal concentrations can pose serious risk to human health. However, the determination of metal levels is usually limited to estimating the concentration of a number of metals in TSP. Although these measurements can give some indication of the general pollution level in an area (*Fernandez et al, 2000*), they don't provide information on the size fractionated metal concentrations.

Trace metals are released into the atmosphere during combustion of fossil fuels and wood as well as during high temperature industrial processes and waste incineration. Natural emission results from a variety of processes acting on crustal minerals, including volcanism, erosion and surface winds, as well as forest fires and oceans. Although estimates for natural sources are uncertain on a global scale, re-suspended surface dusts make a large contribution to the total natural emission of trace metals to the atmosphere, accounting for > 50% of Cr, Mn & V >20% of Cu, Ni, Pb, Zn, Mo, and Sb. While volcanic activities probably generates 20% of atmospheric Cd, Hg, As, Cr, Cu, Ni, Pb and Sb (*Pacyna, 1998*) Sea salt aerosols generated by spray and wave actions may contribute around 10% of total trace metal emissions, while elements contained within biological aerosols are important in forested regions. Cu, Pb and Zn are contained in emissions from bio mass combustion (*Nriagu, 1989*).

A knowledge of the size distribution of atmospheric particles within which trace metals are found is important since this not only influences the toxicity of the metal when inhaled but also controls to the extent which the metals are dispersed via atmospheric transport and hence is a prerequisite for the determination of rate of deposition of metals to the earth's surface. The presence of trace metals in concentration exceeding critical thresholds may cause toxic effects within terrestrial ecosystem (*Berggren et al, 1990*) In the absence of the local industrial or mining activities, a major source of metals is usually the deposition from the atmosphere.

Efficiencies for both inhalation and respiratory deposition are dependent upon particle size (*Hinds, 1999*) and chemical composition mediates toxicity due to the presence of specific toxic elements. (*Spurny, 1998*).

## 1.7 Size Distribution of Aerosols

An essential characteristic of the particles is their size, ranging from a cluster of molecules to 100 $\mu\text{m}$  radius and larger. From the point of view of particle characterization and measurements Junge, (1963) divided aerosol particles in 3 groups.

Aitken particles	$r < 0.1\mu\text{m}$
Large particles	$0.1 \leq r < 1.0\mu\text{m}$
Giant particles	$r \geq 1.0\mu\text{m}$

Since the size of aerosol particles covers several orders of magnitude the concentration alone is not sufficient to characterize the aerosol. For more complete aerosol characterization it is convenient to use a size distribution function. In urban environments a distribution of the form has been often invoked to represent aerosol size distribution.

$$dN/d \log r = c r^{-\beta}$$

Here,  $c$  is the function of concentration while  $\beta$  gives the shape of the distribution curve.

*Whitby (1978)* has analyzed the results of numerous size distribution observations using a combination of expansion chamber, electrical mobility and optical counter technique. Complete size distribution is generally composed of three separate log normal distributions associated with Aitken nuclei mode (0.7  $\mu\text{m}$ ) Accumulation mode (0.1 $\mu\text{m}$ -2.5 $\mu\text{m}$ ) coarse mode (>2.5 $\mu\text{m}$ ).

## 1.8 Necessity of Particle Size Distribution

Size distribution and chemical composition are fundamental aerosol properties most relevant to environment impacts. These along with the abundance or loading are basic physical characteristics of aerosol that are important in determining the radiative



properties. Aerosol size distribution influences the dynamics of aerosol population (*Vakeva et al, 2000*), their production and removal processes, the size transformation, lifetime (*Mc Grow et al 1995*), optical properties and radiative effects. By acting as condensation nuclei, aerosol modifies the microstructure of clouds. Studies of the temporal and spatial changes of aerosol characteristics can also give considerable insight into the origin of particles. In addition to the micro scale aerosol mechanism such as coagulation and condensational growth, large-scale atmospheric processes have profound effects on the size distribution (*Hoppel et al, 1990, Arimoto et al 1997*). In Indian context also a number of studies on characterization of the size distribution of atmospheric aerosols exist.

The reason behind measurement of the size of the particles is that the aerosol parameter best related to the health-effect has not been identified yet. This may be mass or number of particles as was recently demonstrated by *Peter et al (1997)*, Health effect presumably depends on the location at which the particles are preferentially deposited in the respiratory system, which is a function of their size. Particles, which dominate the number concentration are in the so-called ultra fine size range, i.e. have diameter smaller than 100nm. It has been shown that human defense mechanisms is less adapted in combating particles of this size (*Oberdorster et al, 1995*)

Particle size distribution data is essential to assess the inhalation health hazard. (*Trijonis, 1983*). In general, only particles smaller than 10 or 15  $\mu\text{m}$  in size reach the lower respiratory track from the nose to the alveoli (*Mc Cormac, 1971*). Particles with a diameter  $>5\mu\text{m}$  are filtered in nose for the most part, while those  $<1-2\mu\text{m}$  in aerodynamic diameter predominantly gets deposited in the alveolar regions of the lungs where the adsorption efficiency for trace elements is 60 – 80% (*Infante and Acosta, 1991*) and can

effect lung physiology, especially if the particles contain biologically available toxic metals.

The elemental composition is known to differ markedly with particle size (*Seinfeld, 1986*). It has been observed that elements associated with natural sources, such as soil and ocean are usually found with the coarse particulate, while elements emitted from anthropogenic sources are associated with the fine particulate. Fine particles are often the result of vapour conversion to liquid or solid material by the cooling of initially high temperature fumes or by chemical reaction of gases within the atmosphere. By measuring heavy metal concentrations as a function of particle size, information may be obtained concerning which of these possibilities may be the source of releasing the metals into the atmosphere

Different sizes of particulate matters may cause different environmental effects for example; acid rain formation is affected by the high content of chemical aerosols contained in human made pollutants with particle sizes in the range from 0.001 to 2 $\mu$ m. As aerosol size decreases, the PH value and the content of Ca decrease, but the contents of sulphate and ammonium increase. Thus size distribution of aerosols is one of the important factors for acid rain formation (*Zhao and Lin, 1987*).

From the above it is amply clear that knowledge of size distribution of aerosols and metal concentration in different ranges is a pre-requisite in determining the adverse effects on human health. In the Indian context very few studies on aerosol characterization exist. Moreover exhaustive studies on aerosols in the atmospheric environment of Delhi and in particular in areas adjacent to coal based thermal power plants have not been carried out. This has prompted the present study with the sole

objective of measuring the size distribution and the size fractionated metal concentrations in residential areas in the vicinity of a coal-based thermal power plant (National Thermal Power Corporation, Government of India). The details of the study area are given in chapter-II. Materials and Methodology are given in chapter-III. The results are presented and discussed in chapter-IV.

## CHAPTER II

### STUDY AREA

#### 2.1 Geographical Location of Delhi

Delhi, the Capital city of India is situated 160 km south of the Himalayas ( $28^{\circ}21'17''$  to  $28^{\circ}53'$  Latitude and  $76^{\circ}20'37''$  to  $77^{\circ}20'37''$  longitude) at an altitude of between 213.3 and 305.4 m above mean sea level. It is about 1,100 km away from the nearest coast of the North Arabian Sea. The Delhi region is located in the border zone lying between the rich rain washed Gangetic planes to the east and semi arid tracts to the West and South West.

#### 2.2 Climate of Delhi

The climate of Delhi is mainly influenced by the prevalence of Continental air during the major part of the year. Extreme dryness with an intensive hot summer and cold winters is the main characteristics of the climate of the Delhi. The normal rainfall is 611.8 mm except during the monsoon months, winds are predominantly from westerly or westerly directions and tend to be more northerly in the afternoon Easterly and South Easterly winds are more common in the monsoon months. (Srinivas, 1988). January is the coldest month with the mean temperature at  $21.3^{\circ}\text{C}$  and the mean minimum temperature at  $7.3^{\circ}\text{C}$ . May and June are the hottest month of the years where the temperature touches  $46-47^{\circ}\text{C}$ .

Climate and natural sources also play an important role in the pollution level of Delhi in addition to anthropological sources.

Generally low wind speed and temperature inversion conditions, which restrict the mixing height to low levels, lead to an accumulation of air borne pollutants over the city particularly in winter months. In summer, the situation is exacerbated by frequent dust storm. Westerly winds from the Great Indian Desert, Thar Desert of Rajasthan, bring a large amount of Suspended Particulate Matter (SPM), as high as 500-800 tons/sq. miles.

### **2.3 Air Pollution in Delhi**

It is estimated that about 3,000 metric tons of air pollutants are emitted everyday in Delhi. The sources of air pollution in Delhi are: emissions from vehicles (67%) coal based thermal power plants (13%), industrial units (12%) and domestic (8%). In 1991 the air pollutants emitted daily were 1,450 Mt. There has been a rising trend, 1992: 1,700 Mt, 1993: 2,010 Mt, 1994: 2,400 Mt, and 1995: 2,890 Mt.

### **2.4 National Ambient Air Quality Standards:**

The national standards for ambient air quality have been notified under the Air (Prevention and Control of Pollution) Act, 1981 and in the Environment (Protection) Act, 1986.

**Table 1: National Ambient Air Quality Standard**

Pollutant ( $\mu\text{g}/\text{m}^3$ )	Time-Weighed Average	Concentration ( $\mu\text{g}/\text{m}^3$ ) in Ambient Air		
		Industrial	Residential	Sensitive
Suspended Particulate Matter (SPM)	Annual	360	140	704
	24 Hourly	500	200	100
Respirable Particulate Matter (Size less than 10 $\mu\text{m}$ )	Annual	120	60	50
	24 Hourly	150	100	75

**2.5 Thermal Power Plants in Delhi**

There are three power plants in Delhi namely, Badarpur (720MW), Indraprastha (277MW) (coal based and 180 MW gas based) and Rajghat (135 MW). In addition Sriram Food and Fertilizer Industry also has a captive power unit of 32 MW. These Power Plants have been of major concern until recently when the electrostatic precipitators were installed to control the stack emissions. These Power Plants are the major sources of SO<sub>2</sub> emission and they emit an estimated 324 metric tonnes of pollutants every day (inclusive of particulate matter, SO<sub>2</sub>, NO<sub>x</sub>, CO and hydrocarbons), which is 16% of 2020, metric tonnes emitted per day in Delhi (CPCB 1995b).

**Table 2: Thermal Power Stations in Delhi**

S. no.	Power Station	Installed Capacity (MW/day)	Generation (MW/day)	Coal per unit of electricity (kg/KWH)	Million KWH per day
1	BADARPUR	705	502	0.81	14.87
2	I.P. STATION	277.5	136	0.86	2.96
3	RAJGHAT	135	62	0.83	1.93

Among the above-mentioned power plants Badarpur power plant is surrounded by a number of residential colonies. This has been the most important factor in choosing this particular power plant for the present study.

## **2.6 Badarpur Thermal Power Station**

Badarpur is situated in Southeast part of Delhi. It touches the borderline of Delhi and Haryana from Faridabad side. It is mainly a residential area. A thermal power plant (BTPS) is located here. This area is highly polluted due to the combustion of coal in the plant for electricity generation. It supplies the electricity to major part of Delhi. It is operated under the management of National Thermal Power Corporation (NTPC), Government of India.

It has three residential colonies namely New Township, Additional Township and Old Township surrounding it. All these colonies have greenish lustre and are situated at the up-wind location to plume direction. A national highway (Delhi-Mathura highway) nearby its periphery is around 1 Km away from the residential area. The traffic density is very high for most part of the day and moderate to low during night. This area is surrounded by densely populated sub-urban areas.

## **2.7 Sampling sites**

Location of the sampling sites and power stations are shown in fig-1. Five sampling sites were chosen in the vicinity of BTPS. These are as follows:

**2.7.1** NTPC New Township is in up-wind direction to the plume rise. It is within one-Km radius of the BTPS and is northward from it.

- 2.7.2** NTPC Additional Township is also in upwind direction in the vicinity of above site
- 2.7.3** Sector-37, Fariabad is in down-wind direction i.e. toward south of BTPS. It is the nearest colony of Haryana bordering Delhi and is a residential area with local industrial activities.
- 2.7.4** Sector-27, Noida is a residential area with surrounding industrial activities. It is several kilometers away from the source under consideration and therefore is more affected by local environment.
- 2.7.5** Sarita Vihar is a residential area with high traffic density near the site.



## CHAPTER III

### MATERIALS & METHODOLOGY

As mentioned in chapter I, the objective of the present study is the determination of total and size fractionated aerosol concentrations and the metal Ca, Mg, Fe, Cu, Pb, Zn and Ni concentration therein. The details of the instruments used and methods of analysis are presented in the following sections.

#### **3.1 Sampling Equipment**

A five stage Cascade Particulate Sampler (model: CPS – 105; Kimoto, Japan) was used for sampling of the suspended particulate matter. The characteristics of the sampler are summarised in Table 3. The sampler separates particles in the size range 20-0.1 $\mu$ m. The particles of the atmosphere, which go through the ring orifice at each stage, are collected on the surface of the filter paper by impaction. At every stage the particles with specific diameters are separated and deposited on filter paper mounted on each stage. Samples were collected for 24 hours at each site.

Because of the large flow rate of sampling, it is possible to measure the particle distribution with remarkably high precision. Sample flow rate is indicated by rotameter attached to an automatic flow controller that keeps the flow rate constant.

**Table 3: Sampling characteristics of Cascade Particle Sampler (CPS – 105, KIMOTO)**

Stage	Nozzle width (mm)	Flow speed (m/s)	Sampling size ( $\mu\text{m}$ )
1	5.5	3.6	>10.9
2	3	8.0	5.4-10.9
3	1	29.9	1.6-5.4
4	0.5	78.7	0.7-1.6
Back up filter	-	-	<0.7

### 3.2 Collection Media

For estimation of metal concentration, the sample containing filters were analyzed individually. Whatman Glass Microfiber filters (GF/A) are particularly suitable for determination of particulates because of their high retention efficiency combined with low-pressure drop, high resistance of blocking and low alkalinity for moisture. Their size is 20.3 × 25.4cm. The filter paper was cut off to suit the geometrical specification of every stage. Consequently, the paper at every CPS stage is doughnut shaped except the last stage, where a rectangular paper is used. The details of the sizes of the filter papers used for each stage are given in Table 4.

**Table 4: Description of the size of filter papers used in 5 – stage CPS sampler:**

Stage	Shape	Measurements (mm)	
1	Doughnut	197.5 (outer diameter)	171.6 (inner diameter)
2	Doughnut	177.5 (outer diameter)	147.5 (inner diameter)
3	Doughnut	149.5 (outer diameter)	120.6 (inner diameter)
4	Doughnut	132.0 (outer diameter)	97.6 (inner diameter)
5	Rectangular	203 × 354	

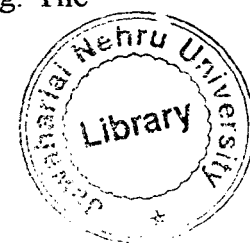
TH-10292

### 3.3 Method of Sampling

Five sets of aerosol samples were collected on previously weighed glass fiber filter papers. These filters are known to absorb water due to their hygroscopic nature resulting in change of weight as a function of humidity. Therefore filters were carefully equilibrated in a dessicator for 48 hours both before and after sampling to eliminate the effect of humidity and thus obtain accurate particulate concentration measurements. An analytical balance (Mettler AE 50) having a precision of 0.1mg was used for weighing of the filter papers. After weighing they were packed into individual plastic bags with an indication label.

### 3.4 Estimation of SPM

SPM was estimated by gravimetry. The mass of aerosol particles collected on each stage was determined by the difference in weights before and after sampling. The



volume of the sampled air was determined by multiplying sampling period with average flow rate. The concentration was then obtained by dividing mass of aerosols by volume of sampled air.

The total suspended particles (TSP) concentration was then determined from the addition of mass concentrations of each fraction.

Calculation for the sample air volume and SPM concentration:

$$V = t \times (Q_i + Q_f) / 2$$

Where

V = Volume (m<sup>3</sup>) of air sampled

Q<sub>i</sub> = Initial flow rate (m<sup>3</sup>/min) at STP

Q<sub>f</sub> = Final flow rate (m<sup>3</sup>/min) at STP

T = Sampling period (min) in Time Totalizer

For calculating the SPM concentration following equation was used:

$$\text{SPM concentration } (\mu\text{g}/\text{m}^3) = 10^6 \times (W_f - W_i)/V$$

Where

W<sub>f</sub> = Weight (gm) of exposed filter papers

W<sub>i</sub> = Weight (gm) of unexposed filter papers

### **3.5 Quantitative Estimation of Metals**

For the characterization of the air particulate matter in a number of urban and industrial environments a number of analytical methods e.g., Atomic Absorption

Spectrometry (AAS), energy dispersive X-ray fluorescence and inductively coupled plasma spectrometry can be used. In the present work the determination of Ca, Mg, Fe, Cu, Zn, Ni and Pb has been done by using AAS (model AA-6800, Shimadzu, Japan).

### 3.5.1 Principle of AAS

Chemical analysis of AAS involves converting the samples, at least partially, into an atomic vapour and measuring the absorbance of the atom at a selected wavelength, which are characteristics of each individual element. The measured absorbance is proportional to the concentration and analysis is done by comparing the absorbance with that given under the same experimental conditions with reference samples of known concentration. Almost all analytical applications of the atomic absorption method at present time involve spraying a solution into a flame.

Beer's law implies, for monochromatic radiation, a linear relationship between absorbance and concentration. However, it can be applicable also if the band of wavelength of the source is narrow with respect to absorption peak. No ordinary monochromatic radiation is capable of yielding a band of radiation as narrow as the peak width of an atomic absorption line (0.002 to 0.005nm). The most common source for atomic absorption measurements is the hollow cathode, which consists of a tungsten anode, and a cylindrical cathode sealed in a glass tube, which is filled with neon or argon at a pressure of 1 to 5 torr. The cathode is constructed of the metal whose spectrum is desired. In this method a majority of free atoms in the commonly used flames remain in the ground state and the flames also do not have enough energy to excite these atoms

except for the group-I elements. Absorption i.e. decrease in energy is then measured by the relation:

$$A = \log (I_0 - I) = abc$$

Where

A = Absorbance

$I_0$  = Intensity of incident radiation

I = Intensity after absorbance

a = Absorption coefficient

b = Path length of radiation through sample

c = concentration

### 3.5.2 Digestion of samples

Per-weighed exposed back-up filter papers were punched into 47mm diameter circular area. Other doughnuts shaped filters were cut into 3 pieces. 1/3. These pieces of filter papers were digested with 1 ml HF and heated to dryness. 3ml HNO<sub>3</sub> was added to this dry mass and again it was heated. At the end nearly 10 ml of distilled water was added and warmed. The solution was, then, filtered with 0.45µm Millipore filter unit (Mille-HV) with the help of a syringe. The filtered volume was made up to 25ml with distilled water.

Unexposed filter papers of each stage were similarly digested for blank and the same procedure was followed.

Acid dilution, using a 3:1 mixture of HNO<sub>3</sub> and HF, has been used by Jalkanen Hasanen (1996) on coal fly ash and urban aerosol samples. The recoveries vary between 80 to 98% for most elements.

### **3.5.3 Preparation of standards:**

#### **3.5.3.1 1000mg Ca/L**

2.498g of calcium carbonate (CaCO<sub>3</sub>) was dissolved in 50ml of deionized water. Approximately 10ml of HCl was added drop wise in the solution. It was diluted to volume in a 1L volumetric flask with deionized water.

#### **3.5.3.2 1000mg Mg/L**

1.000g of magnesium ribbon was dissolved in a minimum volume of 6N HCl and was diluted to volume in a 1L volumetric flask with 2% (v/v) HNO<sub>3</sub>.

#### **3.5.3.3 1000mg Cu/L**

1.000g of copper metal was dissolved in a minimum volume of 6N HCl and was diluted to volume in a 1L volumetric flask with 2% (v/v) HNO<sub>3</sub>.

#### **3.5.3.4 1000mg Fe/L**

1.000g of iron wire was dissolved in a minimum volume of 6N HCl and was diluted to volume in a 1L volumetric flask with 2% (v/v) HNO<sub>3</sub>.

#### **3.5.3.5 1000mg Zn/L**

1.000g of zinc granules was dissolved in a minimum volume of 6N HCl and was diluted to volume in a 1L volumetric flask with 2% (v/v) HNO<sub>3</sub>.

#### **3.5.3.6 1000mg Ni/L**

1.000g of nickel was dissolved in a minimum volume of 6N HCl and was diluted to volume in a 1L volumetric flask with 2% (v/v) HNO<sub>3</sub>.

### **3.5.3.7 1000mg Pb/L**

1.598g of lead nitrate [Pb(NO<sub>3</sub>)<sub>2</sub>] was dissolved in a 2% (v/v) HNO<sub>3</sub> and was diluted to volume in a 1L volumetric flask with deionized water.

### **3.5.4 Analysis of Samples by AAS**

First the instrument was calibrated by aspirating different concentrations of standards. Then concentrations against absorbance of various metals were noted by fixing their specific wavelength.

### **3.5.5 Calculation of metal concentration:**

The metal content ( $X_1$ ) of test portion is expressed in  $\mu\text{g/ml}$ . The content in blank ( $X_2$ ), in the same units, is subtracted from  $X_1$  to get the corrected concentration in the test portion. Multiplication with dilution factor gives the total quantity of the metal in the test sample, in micrograms. For the filters (203mm  $\times$  254mm) the total exposed filter surface area is  $4.159 \times 10^4 \text{ mm}^2$

$$T = (X_1 - X_2) \times f \times 25 / V$$

Where

T = Metal concentration ( $\mu\text{g/m}^3$ )

V = Volume of air sampled ( $\text{m}^3$ )

$X_1$  = Concentration ( $\mu\text{g/ml}$ ) of unknown test solution

$X_2$  = Concentration ( $\mu\text{g/ml}$ ) of blank test solution



25 = Dilution factor

f = Surface multiplication factor

= Filter paper used for digestion / Total filter paper

## CHAPTER IV

### RESULTS AND DISCUSSIONS

The size fractionated aerosol concentrations were measured in the collected samples at various sites following the procedure outlined in the section 3.4. The TSP concentration was obtained after summing up of concentrations of all the 5 stages of the impactor. The sum of SPM concentration in stages 2, 3, 4, and 5 has been taken as an approximate measure of PM10, the concentration representing the respirable suspended particulate matter (RSPM). The concentrations of ultra fine fraction refer to the concentrations of stage 5 only. The sum of the concentrations of stages 4 and 5 denotes the fine fraction.

Fig.2 shows 24 hours average TSP concentrations at all the sites. It may be noted that concentrations are far in excess of permissible standard ( $200\mu\text{g}/\text{m}^3$ ). The maximum concentration  $970\mu\text{g}/\text{m}^3$  is observed at Faridabad followed by New Township, Sarita Vihar, Noida and Additional Township. TSP exceeds the permissible standards by a factor of  $\sim 1.5$  to 5.

RSMP fraction (averaged over 24 hours) at all sites is shown in fig.3. Here again the PM10 concentrations exceed the permissible standard ( $100\mu\text{g}/\text{m}^3$ ) by factor of  $\sim 2.5$  to 5. The maximum PM10 concentration is observed at Sarita Vihar.

The concentrations of fine ( $<1.6\mu\text{m}$ ) and ultrafine ( $<0.7\mu\text{m}$ ) fractions are depicted in fig.4 and 5. Both fine and ultrafine fractions have maximum values at Sarita Vihar. All the above data are provided in Table 5.

The concentration ratios (%) inferred from the fig.2-5 are shown in Table 6. The respirable fraction at all the sites is dominant, in the range 54.22 to 88.96. The fine and ultrafine fractions are 45.18 to 74.93 and 31.27 to 64.26 of TSP respectively. Quite clearly the preponderance of respirable, fine and ultrafine fractions are a serious health hazards at all the sites around the power station. In particular at the site Sarita Vihar, the observed maximum concentrations of fine, ultrafine and PM10 may be attributed to a number of upstream industrial units as well as to the heavy traffic in addition to the emission of power plant.

Next, on examination of size fractionated aerosol concentrations shown in fig.6-10 reveals that particles of size  $<0.7\mu\text{m}$  form the bulk of the SPM at all the sites. However, at Noida and New Township significant amount of aerosols of size  $>10.9\mu\text{m}$  are also seen. The size fractionated aerosols concentration is summarised in Table 5.

The size fractionated metal concentrations are shown in figs.11-15. The value of metal concentrations in size fractionated aerosols for all sites are given in Tables 7(a) and 7(b). It may be inferred from the above figures that Ca is the dominant metal at all the sites. Its concentration is the maximum at site 5. Its presence is mainly associated with coarse particles. At site 5, however, its presence is also significant in fine and ultrafine fractions also. Closely following Ca, significant amount of Mg is found at all the sites. It is interesting to know that the distribution of Mg across various size intervals is fairly even. The next most abundant metal to be found in the aerosol at all sites is Fe. Again the

concentration of the Fe is the maximum at site 5. As in case of Mg, Fe has been found to exist more or less across all size intervals, although its presence is relatively more biased towards coarse particles. Significant amount of Cu has also been found to exist at each site. The distribution of Cu in various size intervals appears to be quite random. The presence of Zn closely resembles the behaviours of Cu across all the sites. The association of Zn in various size fractions, again seems to be random, similar to the case of Pb which is supposed to be of serious concern in environment, is not found in very significant amount at any of the sites. Finally, the analysis of Ni did not indicate its presence in aerosols at any of the sites probably because its concentration may well have been far below the detection limit of AAS.

In an attempt to gain further insight into physical and chemical characteristics of aerosols, correlation and regression analyses were carried out

1. Between various aerosol size fractions, and
2. Between different metal concentrations.

In the case of size fractionated aerosols significant correlations were found between PM10 and TSP; PM10 and fine; PM10 and ultrafine; and ultrafine and fine. All the results are shown in Tables-8 (a) and (b).

Regression analysis was carried out for different combinations of size-fractionated aerosols. Among different regression exercises, the results in the following cases are found to be significant at 10% level of significance:

1. TSP was regressed on fine and ultrafine
2. TSP was regressed on ultrafine and PM10
3. TSP was regressed on fine and PM10

4. Ultrafine was regressed on PM10
5. Ultrafine was regressed on fine
6. Fine was regressed on PM10
7. PM10 was regressed on TSP

Estimated regression coefficients are given in Tables 9(a)-15(b). It may be noted that the standard errors are also low for all these cases.

The model equations can be written as:

1.  $[TSP] = 128.42 - 4.057908 [Ultrafine] + 4.545007 [Fine]$   $R^2 = 0.9380$
2.  $[TSP] = 56.451185 + 1.958821 [PM10] + 1.003218 [ultrafine]$   $R^2 = 0.9803$
3.  $[TSP] = -101.045675 + 2.46367 [PM10] - 1.357045 [Fine]$   $R^2 = 0.9750$
4.  $[Ultrafine] = -67.789543 + 0.754994 [PM10]$   $R^2 = 0.7629$
5.  $[Ultrafine] = -15.492781 + 0.864520 [Fine]$   $R^2 = 0.9575$
6.  $[Fine] = -82.97600 + 0.930164 [PM10]$   $R^2 = 0.9038$
7.  $[PM10] = 42.023534 + 0.726250 [TSP]$   $R^2 = 0.8725$

The equation 1. expressing the model results implies that the 93% variation in the TSP concentration can be attributed to the variations in the concentration of fine and ultrafine fractions.

The results of correlation analysis of metals are provided in Table 16. It may be inferred that among these metals Cu, Fe and Zn are highly correlated with 10% level of significance.

The regression analysis was carried out for various combinations of metal concentrations. Estimated regression coefficients are given in Tables 17(b). The best

regression model results are obtained when Cu as dependent variable is regressed with Ca, Fe and Mg as explanatory or independent variables.

Model equation for the above case is

$$[\text{Cu}] = 7.038448 + 0.017349 [\text{Ca}] + 0.163488 [\text{Fe}] - 0.927311 [\text{Mg}] \quad R^2 = 0.9999$$

The above equation expressing the model results implies that the 99% variations in the Cu concentration can be accounted for by the variations in the concentrations of Ca, Fe and Mg.

The t statistics associated with parameter estimates and the F-values in Analysis of Variance point towards the excellent goodness of fit of the relationship expressed by the above model equation.

Since the present study pertains to the mass size distribution of aerosols and associated metal concentration in them, it will be worthwhile estimating the number of particles in various size intervals and thus obtain particle number size distribution also. Moreover, Principal Component Analysis and Factor Analysis should be carried in order to identify the aerosol sources and their share of respective contributions to the aerosol load in the ambient environment.

**Table 5: Mass concentration of size fractionated Aerosols, TSP, PM10, Ultrafine and fine fractions**

<0.7	208.3740694	128.9828431	260.558668	165.61819	390.406162
0.7-1.6	92.67796172	35.64133987	51.2839028	26.059162	64.7759104
<b>Size range</b>	<b>New township</b>	<b>Additional township</b>	<b>Faridabad</b>	<b>Noida</b>	<b>Sarita Vihar</b>
1.6-5.4	111.0066981	44.73039216	70.7982354	59.345671	61.2743098
5.4-10.9	60.20296801	42.0751634	40.3452308	47.435819	15.7563025
>10.9	194.141033	52.18545752	52.4651147	81.943851	75.280112
<b>TSP</b>	666.4027302	303.6151961	475.451152	380.4027	607.492997
<b>PM 10</b>	472.2616972	164.624183	422.986037	298.45884	532.212885
<b>Ultrafine</b>	208.3740694	128.9828431	260.558668	165.61819	390.406162
<b>Fine</b>	301.0520311	164.624183	311.842571	191.67735	455.182073

**Table 6: Concentration ratios**

	<b>PM10 / TSP</b>	<b>Fine fraction / TSP</b>	<b>Ultra fine fraction / TSP</b>
<b>New township</b>	70.867311	45.17568993	31.26848974
<b>Additional township</b>	54.221325	54.22132526	42.48234107
<b>Faridabad</b>	88.965193	65.58877177	54.80240546
<b>Noida</b>	78.458657	50.38801177	43.537597
<b>Sarita Vihar</b>	87.608069	74.92795389	64.26512968



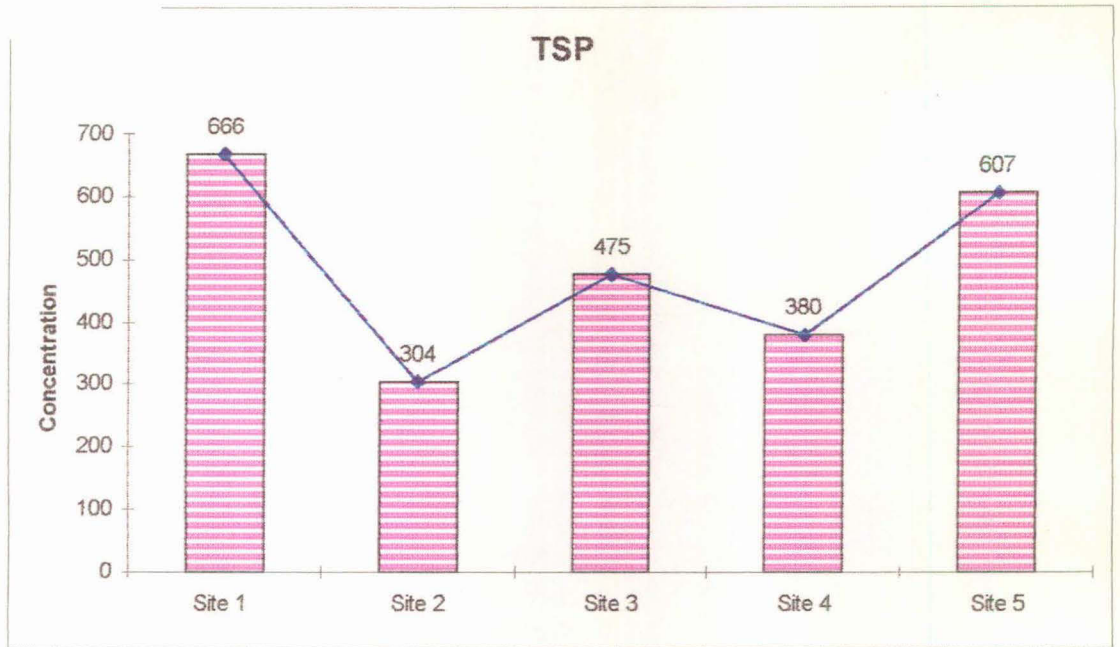
**Table 7 (a): Metal (Mg, Ca and Cu) concentration ( $\mu\text{g}/\text{m}^3$ ) in size fractionated aerosols and TSP in each site**

	<b>Size range</b>	<b>Site I</b>	<b>Site II</b>	<b>Site III</b>	<b>Site IV</b>	<b>Site V</b>
<b>Mg</b>	<0.7	1.998809	1.980376	3.034953	1.960752	1.854922
	0.7-1.6	1.672445	1.524561	1.601168	1.656536	1.5729
	1.6-5.4	1.699545	1.797461	1.711638	1.864608	1.822853
	5.4-10.9	1.847484	1.443558	0.998966	1.491442	1.476865
	>10.9	1.265658	1.353276	0.987124	1.405298	1.389279
	TSP	8.483942	8.099232	8.333848	8.378636	8.116818
<b>Ca</b>	<0.7	1.549323	1.136612	4.627952	1.635497	3.131303
	0.7-1.6	2.980604	0.523396	2.035845	1.85504	2.948608
	1.6-5.4	1.598606	1.986688	4.207841	3.477692	2.934244
	5.4-10.9	1.59446	1.869547	4.585047	3.999588	5.772164
	>10.9	2.438816	0.343919	5.730319	4.932144	7.494748
	TSP	10.16181	5.860161	21.187	15.89996	22.28107
<b>Cu</b>	<0.7	0.037343	0.013572	0.250664	0.017162	0.740021
	0.7-1.6	0.050374	0.024035	0.021017	0.042875	0.581933
	1.6-5.4	0.068573	0.0339	0.009456	0.035088	0.952206
	5.4-10.9	0.106454	0.016437	0.009026	0.025744	0.339811
	>10.9	0.035059	0.014614	0.0093	0.032493	0.388918
	TSP	0.297803	0.102558	0.299463	0.153362	3.002889

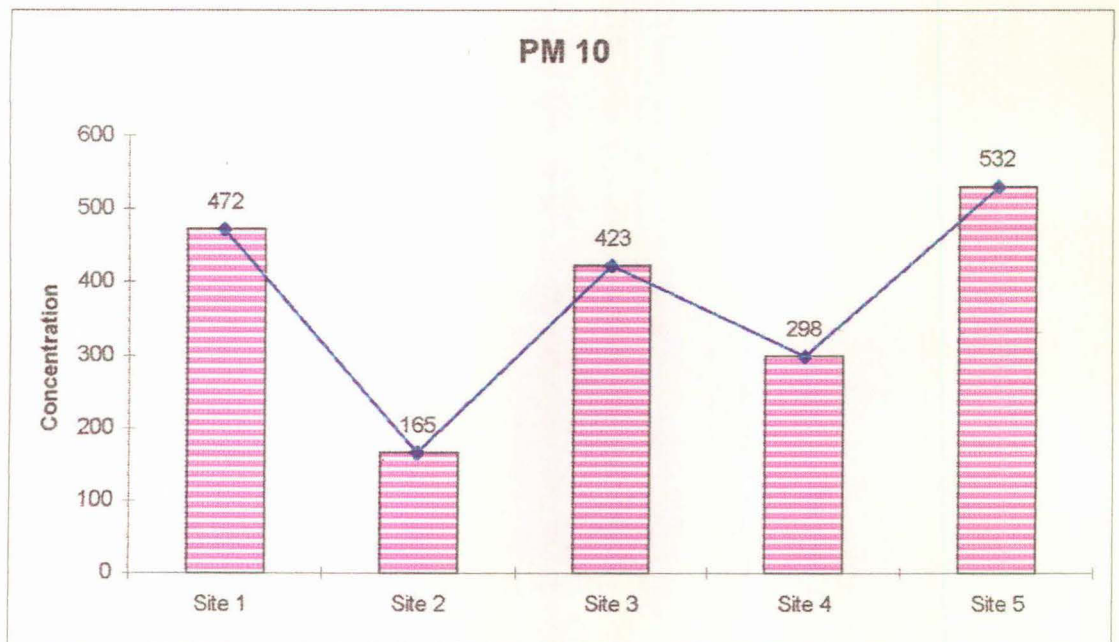
**Table 7 (b): Metal (Fe, Zn and Pb) concentration ( $\mu\text{g}/\text{m}^3$ ) in size fractionated aerosols and TSP in each site**

	<b>Size range</b>	<b>Site I</b>	<b>Site II</b>	<b>Site III</b>	<b>Site IV</b>	<b>Site V</b>
<b>Fe</b>	<0.7	0.653576	0.456005	1.029842	0.471416	2.453782
	0.7-1.6	0.640381	0.359283	0.732192	0.48099	2.638655
	1.6-5.4	1.423223	0.656817	0.63685	0.97473	6.064863
	5.4-10.9	1.364477	0.571048	0.5992	0.772766	3.736082
	>10.9	1.695703	0.84205	0.745976	1.119938	4.10084
	<b>TSP</b>	<b>5.777359</b>	<b>2.885202</b>	<b>3.74406</b>	<b>3.819841</b>	<b>18.99422</b>
<b>Zn</b>	<0.7	0.041081	0.042218	0.147474	0.053564	0.855567
	0.7-1.6	0.040531	0.014384	0.010158	0.029164	0.534664
	1.6-5.4	0.029316	0.033915	0.059179	0.055961	1.107747
	5.4-10.9	0.045075	0.014844	0.017647	0.019346	0.403099
	>10.9	0.005129	0.005438	0.031822	0.023759	0.49895
	<b>TSP</b>	<b>0.161132</b>	<b>0.1108</b>	<b>0.26628</b>	<b>0.181793</b>	<b>3.400026</b>
<b>Pb</b>	<0.7	0.003859	0.0001	0.001498	0.0003	0.0001
	0.7-1.6	0.035243	0.045634	0.00015	0.0001	0.0002
	1.6-5.4	0.022521	0.009314	0.00015	0.0001	0.0002
	5.4-10.9	0.012009	0.0001	0.00025	0.0002	0.0001
	>10.9	0.001954	0.0001	0.0001	0.0001	0.0001
	<b>TSP</b>	<b>0.075587</b>	<b>0.055248</b>	<b>0.002148</b>	<b>0.0008</b>	<b>0.0007</b>

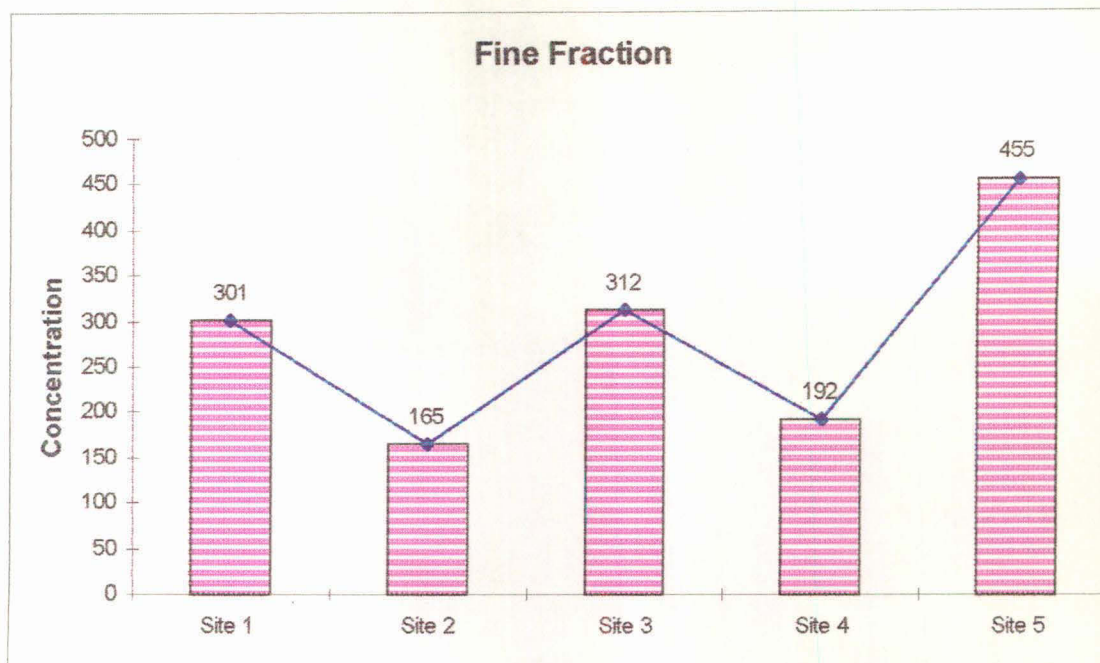
**Fig 2: Concentration ( $\mu\text{g}/\text{m}^3$ ) of TSP in each site**



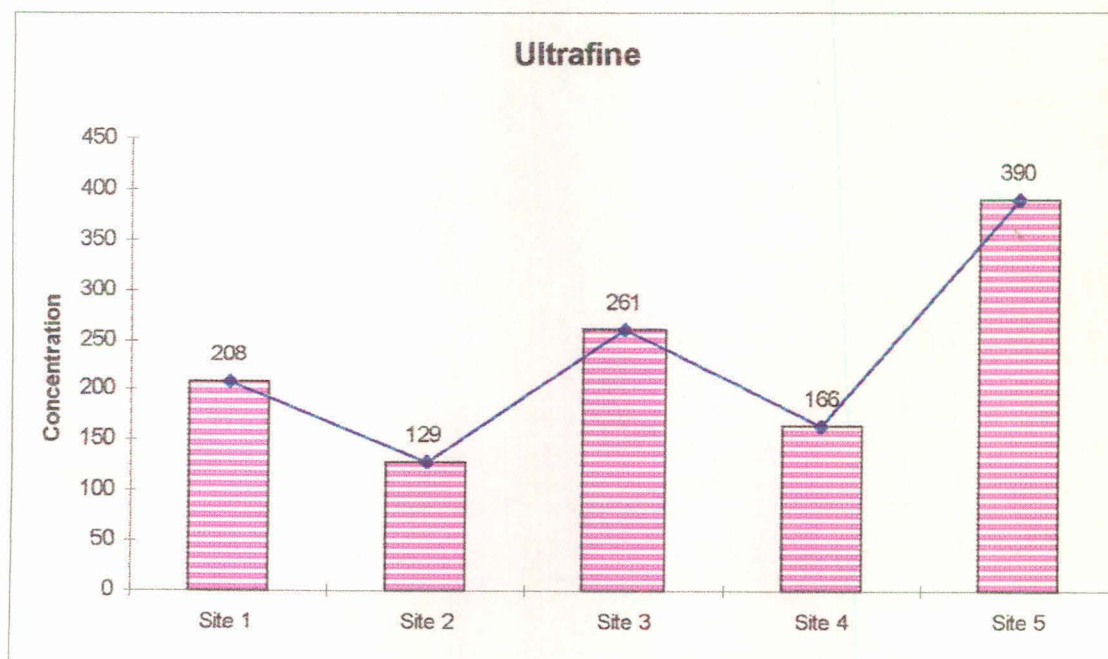
**Fig 3: Concentration ( $\mu\text{g}/\text{m}^3$ ) of PM10 in each site**



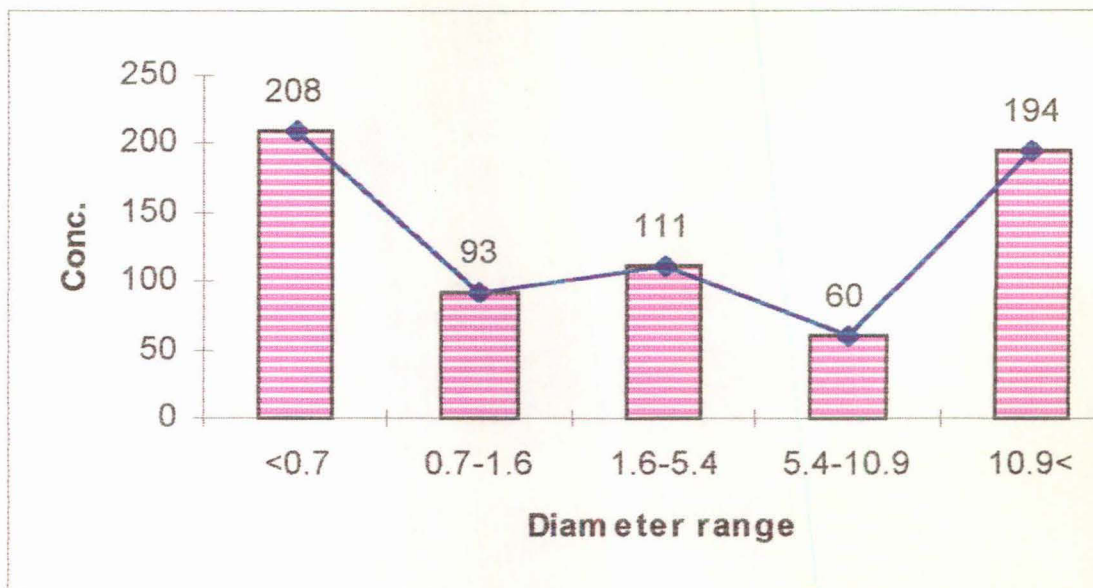
**Fig 4: Concentration ( $\mu\text{g}/\text{m}^3$ ) of Fine fraction in each site**



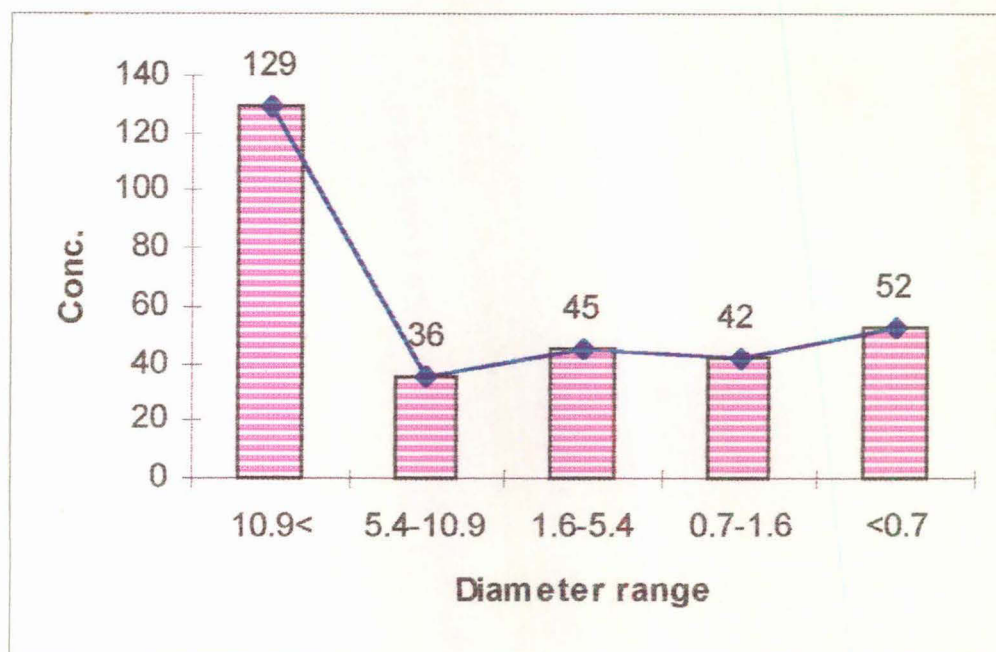
**Fig 5: Concentration ( $\mu\text{g}/\text{m}^3$ ) of Ultrafine fraction in each site**



**Fig 6: Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of aerosols in New Township**

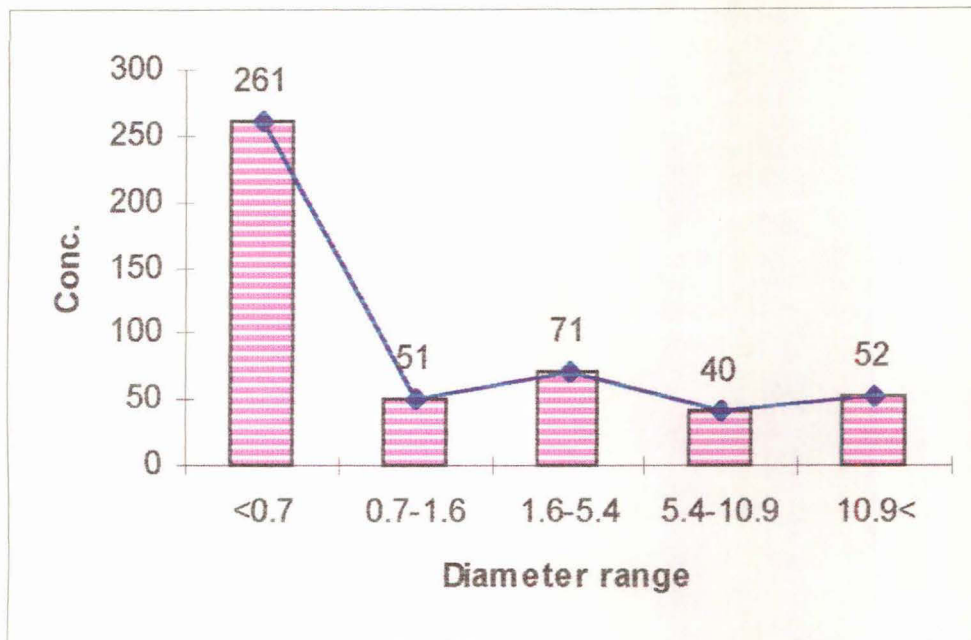


**Fig 7: Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of aerosols in additional township**

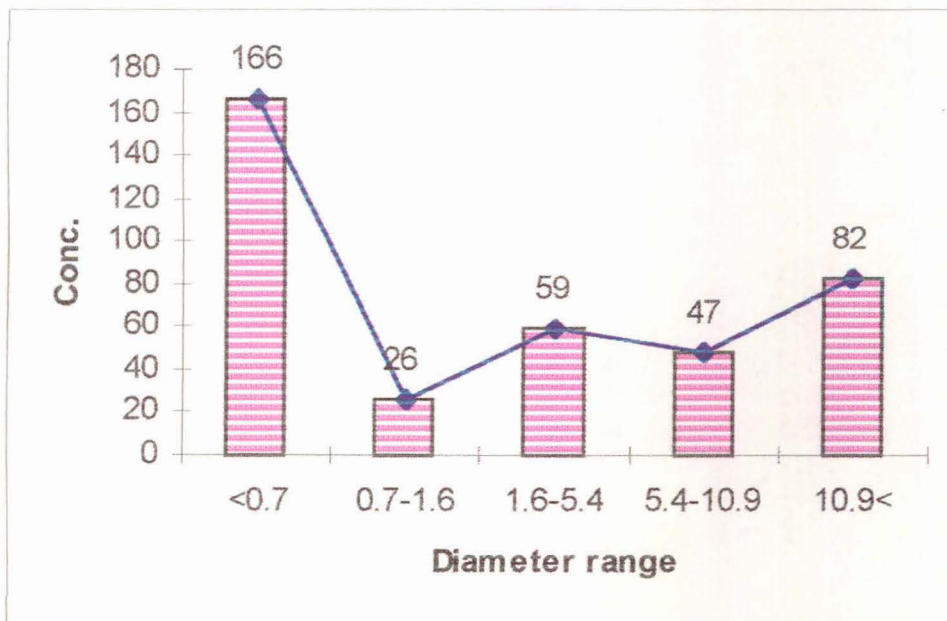




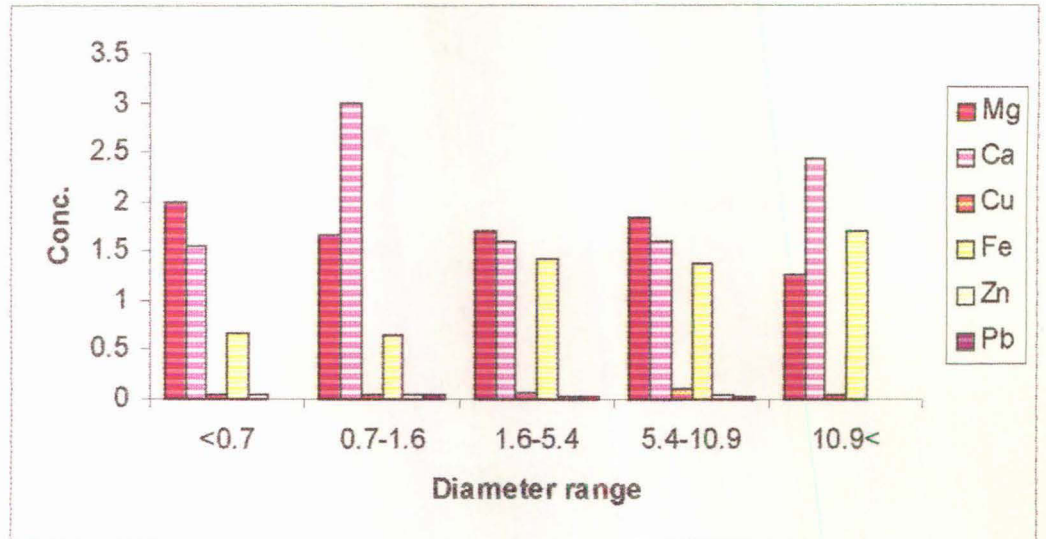
**Fig 8: Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of aerosols Faridabad**



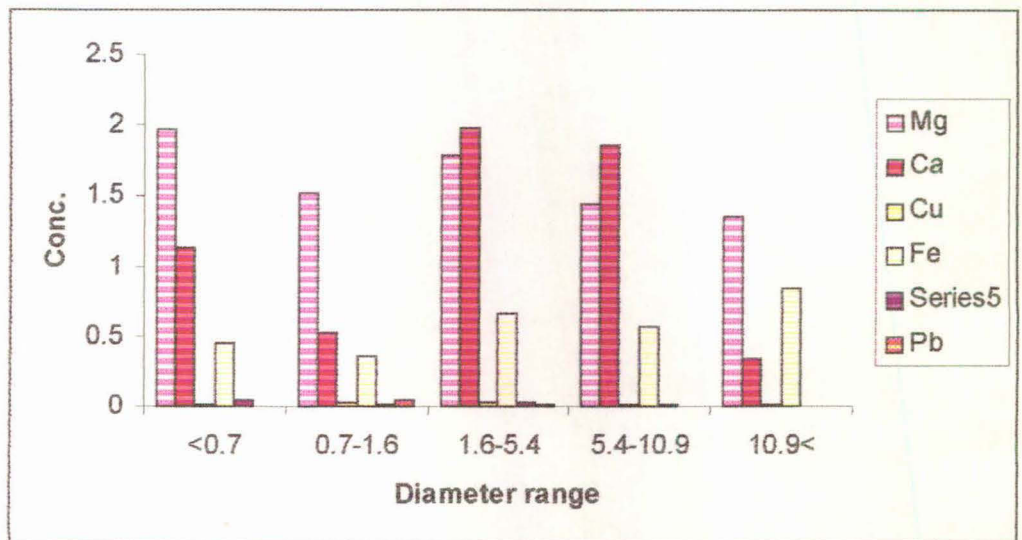
**Fig 9 Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of aerosols in Noida**



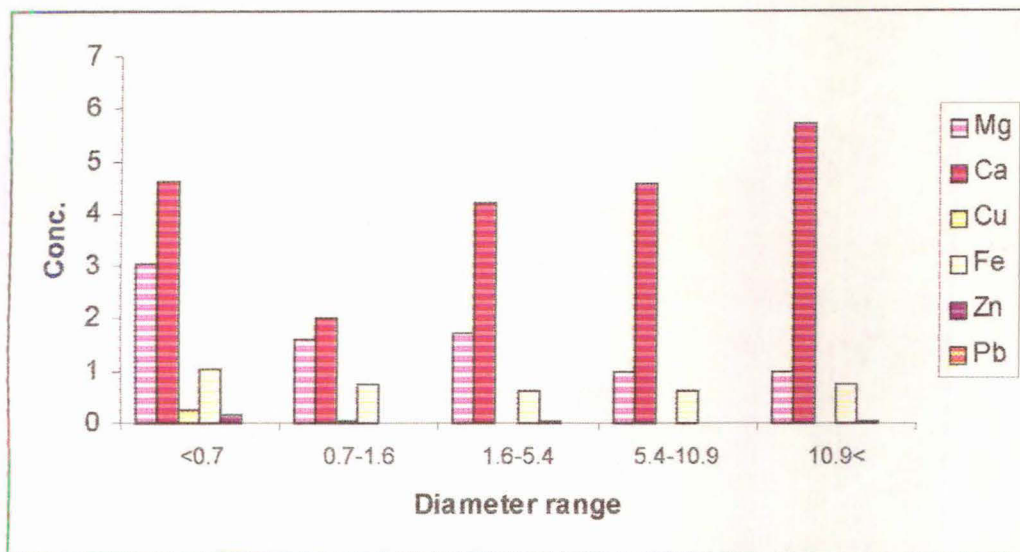
**Fig 11: Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of metals in New Township**



**Fig 12: Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of metals in Additional Township**



**Fig 13: Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of metals in Faridabad**



**Fig 14: Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of metals in Noida**

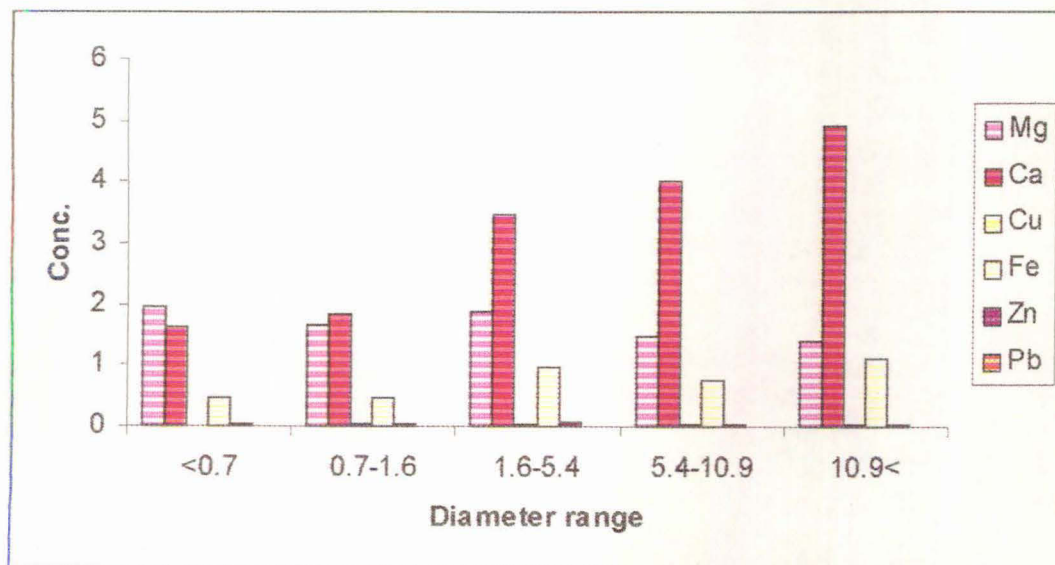
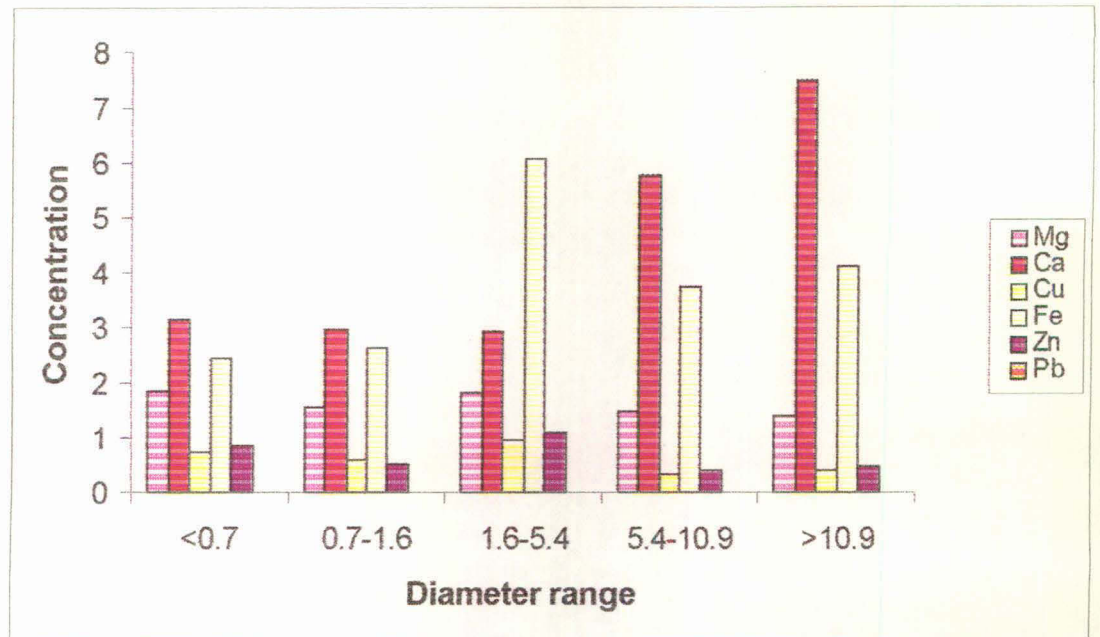




Fig-15 Size fractionated concentration ( $\mu\text{g}/\text{m}^3$ ) of metals in Sarita Vihar



## Correlation Analysis

Variables: TSP, PM10, Ultrafine and Fine

**Table 8(a): Simple Statistics**

Variable	No.	Mean	Std Dev	Sum	Minimum	Maximum
<b>TSP</b>	5	486.7	151.5	2433.4	303.6	666.4
<b>PM10</b>	5	378.1	147.1	1890.5	164.6	532.2
<b>Ultra fine</b>	5	230.8	101.8	1153.9	129.0	390.4
<b>Fine</b>	5	284.9	115.3	1424.4	164.6	455.2

**Table 8(b): Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 5**

	<b>TSP</b>	<b>PM10</b>	<b>Ultrafine</b>	<b>Fine</b>
<b>TSP</b>	1.00000	0.92633	0.65597	0.78875
	0.0	0.0237	0.2293	0.1128
<b>PM10</b>	0.92633	1.00000	0.84700	0.91532
	0.0237	0.0	0.0702	0.0292
<b>Ultrafine</b>	0.65597	0.84700	1.00000	0.97853
	0.2293	0.0702	0.0	0.0038
<b>Fine</b>	0.78875	0.91532	0.97853	1.00000
	0.1128	0.0292	0.0038	0.0

## Regression Analysis

**Dependent Variable: TSP**

**Table 9(a): Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
<b>Model</b>	2	86140.51168	43070.25584	15.141	0.0620
<b>Error</b>	2	5689.20305	2844.60153		
<b>C Total</b>	4	91829.71473			

Root MSE	53.33481	R-square	0.9380
Dep Mean	486.67295	Adj R-sq	0.8761
C.V.	10.95907		

**Table 9(b): Parameter Estimates**

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob >  T
<b>Intercept</b>	1	128.427796	72.80598589	1.764	0.2198
<b>Ultra fine</b>	1	-4.057908	1.27066467	-3.194	0.0856
<b>Fine</b>	1	4.5450075	1.12261607	4.049	0.0559

## Regression Analysis

**Dependent Variable: TSP**

**Table 10(a): Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	2	90021.77815	45010.88908	49.793	0.0197
Error	2	1807.93658	903.96829		
C Total	4	91829.71473			

Root MSE	30.06607	R-square	0.9803
Dep Mean	486.67295	Adj R-sq	0.9606
C.V.	6.17788		

**Table 10(b): Parameter Estimates**

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob >  T
Intercept	1	56.451185	56.12453890	1.006	0.4204
PM10	1	1.958821	0.26205629	7.475	0.0174
Ultrafine	1	1.003218	0.30316350	-3.309	0.0805

## Regression Analysis

**Dependent Variable: TSP**

**Table 11(a): Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
<b>Model</b>	2	89534.59673	44767.29836	39.011	0.0250
<b>Error</b>	2	2295.11800	1147.55900		
<b>C Total</b>	4	91829.71473			

Root MSE	33.87564	R-square	0.9750
Dep Mean	486.67295	Adj R-sq	0.9500
C.V.	6.96066		

**Table 11(b) Parameter Estimates**

Variable	DF	Parameter estimate	Standard error	T for H0:Parameter=0	Prob >  T
<b>Intercept</b>	1	-101.045675	70.77121249	-1.428	.2895
<b>PM10</b>	1	2.463671	0.46362100	5.314	.03361
<b>Fine</b>	14	-1.357045	0.47385529	-2.864	.1034

## Regression Analysis

**Dependent Variable: Ultrafine**

**Table 12(a) Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
<b>Model</b>	1	31642.46230	31642.46230	9.651	0.0530
<b>Error</b>	3	9835.56621	3278.52207		
<b>C Total</b>	4	41478.02851			

Root MSE	57.25838	R-square	0.7629
Dep Mean	230.78799	Adj R-sq	0.6838
C.V.	24.80995		

**Table 12(b): Parameter Estimates**

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob >  T
<b>Intercept</b>	1	-67.789543	99.46112792	-0.682	0.5444
<b>PM10</b>	1	0.754994	0.24302317	3.107	0.0530

## Regression Analysis

**Dependent Variable: Ultrafine**

**Table 13(a): Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
<b>Model</b>	1	39716.21664	39716.21664	67.628	0.0038
<b>Error</b>	3	1761.81187	587.27062		
<b>C Total</b>	4	41478.02851			

Root MSE	24.23367	R-square	0.9575
Dep Mean	230.78799	Adj R-sq	0.9434
C.V:	10.50040		

**Table 13(b) Parameter Estimates**

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob >  T
Intercept	1	-15.492781	31.84851744	-0.486	0.6600
fine	1	0.864520	0.10512606	8.224	0.0038

## Regression Analysis

Dependent Variable: Fine

**Table 14(b) Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
<b>Model</b>	1	48028.76779	48028.76779	28.193	0.0130
<b>Error</b>	3	5110.73749	1703.57916		
<b>C Total</b>	4	53139.50528			

Root MSE	41.27444	R-square	0.9038
Dep Mean	284.87564	Adj R-sq	0.8718
C.V.	14.48858		

**Table 14(b) Parameter Estimates**

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob >  T
<b>Intercept</b>	1	-82.97600	71.69609202	-1.157	0.3309
<b>PM10</b>	1	0.930164	0.17518212	5.310	0.0130



## Regression Analysis

Dependent Variable: PM10

**Table 15(a): Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
<b>Model</b>	1	48434.59875	48434.59875	20.532	0.0201
<b>Error</b>	3	7076.87608	2358.95869		
<b>C Total</b>	4	55511.47483			

Root MSE	48.56911	R-square	0.8725
Dep Mean	395.46984	Adj R-sq	0.8300
C.V.	12.28137		

**Table 15(b) Parameter Estimates**

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob >  T
<b>Intercept</b>	1	42.023534	80.96977469	0.519	0.6396
<b>TSP</b>	1	0.726250	0.16027602	4.531	0.0201

**Table 16: Correlation Analysis**

**Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0 / N = 5**

	<b>Mg</b>	<b>Ca</b>	<b>Cu</b>	<b>Fe</b>	<b>Zn</b>	<b>Pb</b>
<b>Mg</b>	1.00000	-0.02140	-0.50579	-0.42840	-0.53553	0.21388
	0.0	0.9728	0.3846	0.4717	0.3523	0.7298
<b>Ca</b>	-0.02140	1.00000	0.60014	0.56504	0.60139	-0.85113
	0.9728	0.0	0.2846	0.3209	0.2833	0.0674
<b>Cu</b>	-0.50579	0.60014	1.00000	0.99301	0.99867	-0.40470
	0.3846	0.2846	0.0	0.0007	0.0001	0.4992
<b>Fe</b>	-0.42840	0.56504	0.99301	1.00000	0.98746	-0.33652
	0.4717	0.3209	0.0007	0.0	0.0017	0.5798
<b>Zn</b>	-0.53553	0.60139	0.99867	0.98746	1.00000	-0.43211
	0.3523	0.2833	0.0001	0.0017	0.0	0.4675
<b>Pb</b>	0.21388	-0.85113	-0.40470	-0.33652	-0.43211	1.00000
	0.7298	0.0674	0.4992	0.5798	0.4675	0.0

## Regression analysis

Dependent Variable: Cu

**Table 17(a): Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
<b>Model</b>	3	6.25551	2.08517	5569.563	0.0098
<b>Error</b>	1	0.00037	0.00037		
<b>C Total</b>	4	6.25588			

Root MSE 0.01935  
 Dep Mean 0.77121  
 C.V. 2.50891

R-square 0.9999  
 Adj R-sq 0.9998

**Table 17(b): Parameter Estimates**

Variable	DF	Parameter Estimate	Standard Error	T for H0: Parameter=0	Prob >  T
<b>Intercept</b>	1	7.038448	0.55098119	12.774	0.0497
<b>Ca</b>	1	0.017349	0.00174035	9.968	0.0637
<b>Fe</b>	1	0.163488	0.00200814	81.413	0.0078
<b>Mg</b>	1	-0.927311	0.06654387	-13.935	0.0456

## **CHAPTER V**

### **CONCLUSIONS**

- 1** TSP far exceeds permissible standards at all the sites.
- 2** RSPM far exceeds permissible standards at all the sites.
- 3** Most of the aerosols are in fine and ultrafine size range.

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