

ASSESSMENT OF BREATHING LEVEL AIR QUALITY IN SHILLONG



By

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DEPARTMENT OF CHEMISTRY**

**THESIS SUBMITTED IN FULFILMENT OF THE
REQUIREMENT FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY IN CHEMISTRY**

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April, 2002

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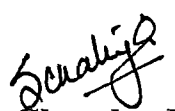
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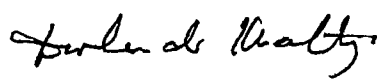
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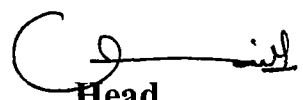
I, **Sarvesh Chandra Katiyar**, hereby, declare that the subject matter of this thesis entitled “**ASSESSMENT OF BREATHING LEVEL AIR QUALITY IN SHILLONG**” is the record of work done by me, that the content of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the North Eastern Hill University for the degree of **DOCTOR OF PHILOSOPHY** in Chemistry.


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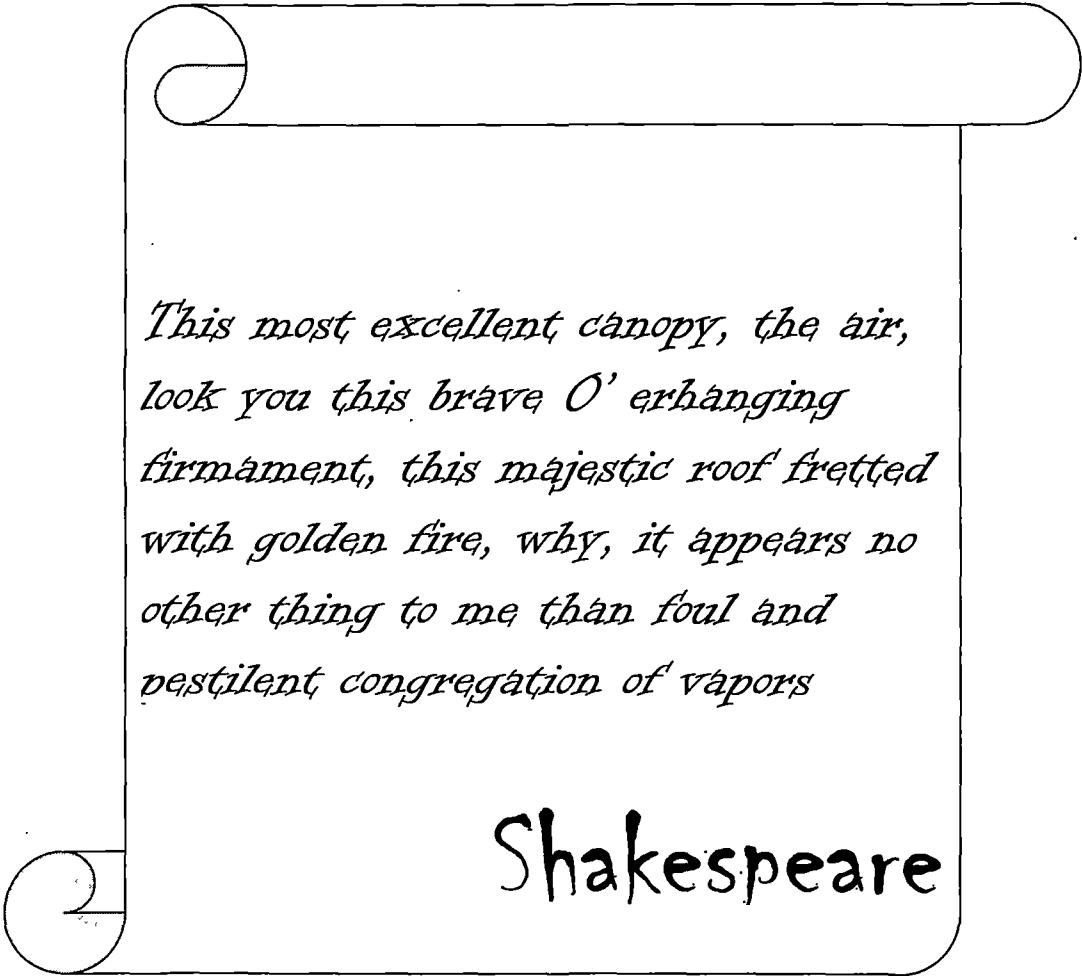
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*This most excellent canopy, the air,
look you this brave O' erhanging
firmament, this majestic roof fretted
with golden fire, why, it appears no
other thing to me than foul and
pestilent congregation of vapors*

Shakespeare

CHAPTER 1

CHAPTER 1

AIR POLLUTION-AN OVERVIEW

1.1 INTRODUCTION

The environment, defined as the outer physical and biological system in which man and other organisms live, is a complex web with several interacting strands. The environmental balance is a result of the natural evolution of these interacting strands over time. Until the recent past, human beings lived in complete harmony with environment since their existence on the planet earth for about five million years. The quest for better living standards together with wanton greed to possess more guided man to start exploiting the exhaustible environmental resources in a most unsustainable manner. The advent of the 20th century witnessed fast technological advancements leading to massive industrialization and rapid agricultural growth. This in concert with population explosion, unprecedented urbanization and socio-economic boom put added pressure on our fragile environment and shattered its equilibrium in an irreversible manner. These imbalances caused by man's activities to their pristine environment are termed as "*Environmental Pollution*".

Environmental Pollution affects all four segments of the earth, viz. atmosphere, hydrosphere, lithosphere and biosphere. Amongst the pollution problems of various segments of the environment, the problem of atmosphere or air pollution attains greater significance due to its natural life sustaining quality. Its protective blanket of gases saves the earth from the hostile environment of outer space by absorbing most of the cosmic rays and a major portion of the electromagnetic radiations from the Sun transmitting only near ultraviolet, visible, near infrared radiation (300-2500 nm) and radio waves (0.01-40 μm) whilst filtering out tissue damaging ultra violet radiations of below 300 nm. The atmosphere plays a key role in maintaining the heat balance of the earth by absorbing infrared radiations received from the Sun and that reemitted from the earth. It is a storehouse of oxygen, essential for life on earth and carbon dioxide, required by plants for photosynthesis. It also makes available nitrogen to nitrogen fixing bacteria and ammonia manufacturing plants to yield chemically bound nitrogen essential for life. In addition, it is a vital carrier of water from oceans to land as a part of the hydrological cycle. Moreover, it acts as a carrier of sound too.

Air Pollution is one of the most threatening problems inherited by the 21st century. It is no longer a problem of urban centres alone as it has pervaded even to the remote areas. Air pollution is a global predicament since geographical dimensions cannot restrict the transport of air pollutants.

The origin of air pollution on earth can be traced back from the times when man discovered fire and started using it as means for cooking and space heating. However, the first documentation of the problem may have been the Roman

complaints of the foulness of their city's air. The hazard of smoke pollution was first recognized in London in year 1273 when coal burning for domestic heating was restricted by promulgation of an anti-pollution law (Trivedy *et al.*, 1995). The menace of smoke pollution emerged as a severe problem only from late 18th century with the start of the industrial revolution leading to large scale burning of coal. As industrialization and development continued to grow all over the world, the increase in atmospheric pollution also continued giving rise to air pollution episodes due to smog in Meuse valley, Belgium, 1930, Donora, Pennsylvania, 1948, and London, 1952. In all these incidences a large number of deaths and morbidity cases were recorded. These incidences led to promulgation of the first U.S Federal Legislation in 1955 and passing of the Clean Air Act in Britain in 1956 and later to very extensive air pollution studies in most of the developed nations.

In India, the problem of air pollution was officially recognized in the early nineteen eighties. The promulgation of the Air (Prevention and Control of Pollution) Act, 1981 was the first step by the Govt of India to contain the problem of air pollution in the country.

Methyl Isocyanate (MIC) gas leak disaster in Bhopal, India during the night of 3rd December 1984 was perhaps the worst industrial disaster in the history of mankind, which left about 3000 people dead and 2 lakhs seriously affected. It was observed that the provisions contained in the Air (Prevention and Control of Pollution) Act, 1981 were not adequate to deal with such industrial catastrophes and this led to the promulgation of the Environment (Protection) Act, 1986, a powerful umbrella Act to deal with all environmental pollution problems of the country. With

the growing concern among the masses about air pollution hazards, the smoke spewing stacks no longer remained sights of the industrial development but became points of concern. Notification of industrial emission standards for various industries, ambient air quality standards, vehicular exhaust emission standards and taking up of the National Air Monitoring Programme (NAMP) are a few examples that depict the seriousness on the part of the government to deal with the increasing problems of air pollution in the country.

The term “*Air Pollution*” has been defined in many ways. As per the definition developed by World Health Organization’s Working Committee (WHO, 1972) air pollution is “limited to the situations in which the outdoor ambient atmosphere contains materials in such concentrations which are harmful to man or his environment”. The Air (Prevention and Control of Pollution) Act, 1981 (CPCB, 1996) defines air pollution as “the presence in the atmosphere of any air pollutant, which in turn is defined as solid, liquid or gaseous substance present in atmosphere in such concentration as may be or tend to be injurious to human beings or other living creatures or plants or property or environment”.

1.2 MAJOR AIR POLLUTANTS AND THEIR SOURCES

Composition of ambient air continuously changes depending on the kind and concentration of air pollutants it receives. Air pollutants may be of natural or anthropogenic origin (PCEH, 1988b). Natural sources of air pollutants include windblown dust, volcanic ash and gases, ozone from lightning and ozone layer, esters and terpenes from vegetation, smoke, gases and fly ash from forest fires, pollens and

other aeroallergens, gases and odors from natural decomposition and natural radioactivity. This source constitutes background pollution concentrations and control strategies have very little or no impact on such problems.

Anthropogenic sources cover a wide spectrum of chemical and physical activities and a number of pollutants are emitted into the atmosphere. However, World Health Organization (WHO, 1972) identifies six main pollutants i.e. Suspended particulates, Sulfur dioxide (SO_2), Nitrogen oxides (NO_x), Carbon monoxide (CO), Oxidants and Lead (which was included later) because of their international significance, common occurrence in many countries and severity of their potential health effects on man (Suess, 1979).

Air pollutants can also be classified as origin and states of matter. Origin pollutants are primary - emitted to the atmosphere from a process and secondary - formed in the atmosphere as a result of chemical reactions. The states of matter pollutants are gaseous - true gases such as SO_2 , NO_x , CO, ozone etc. and vapors such as gasoline (petrol), paint solvents, dry cleaning agents etc. and particulates - finely divided solid particles such as dust, fumes and smoke and liquid particles such as droplets, mists, fogs and aerosols. Natural cleansing processes remove a good part of these emissions. The leftover part remains in the atmosphere for different periods depending on its residence time.

In the present scenario, suspended particulate matters, toxic elements, SO_2 , NO_x , CO, oxidants and organic compounds like Volatile organic compounds (VOC's), Polycyclic aromatic hydrocarbons (PAH's), Polychlorinated biphenyls (PCB's) etc. are the key pollutants. The major sources of these pollutants are

transportation, fuel combustion, industrial processes, solid wastes disposal and other miscellaneous sources. Suspended particulate matters and toxic elements are discussed in brief in following sub-sections as these are within the ambit of the present study:

1.2.1 Suspended particulate matters

Particulate matter, the oldest air pollution problem known to mankind, is a mixture of solid and liquid particulates of varying sizes, shapes and chemical composition suspended in the atmosphere (Schwartz *et al.*, 1996). It is also referred to as suspended particulate matter (SPM) and total suspended particulates (TSP). The characteristics of TSP vary from place to place depending upon types of emission sources and meteorological conditions. The major anthropogenic activities responsible for elevated levels of TSP in urban atmosphere are industrial emissions, domestic fuel burning, solid waste disposal and vehicular exhaust emissions. Gas-particle conversion is the secondary source of TSP in the atmosphere. Concentration of dust particles in urban atmosphere is considered to be higher by a factor of 10 times than rural atmosphere (EEH, 1997) because of higher anthropogenic activities. Available statistics for TSP emissions in three

Table 1.1 Estimated emissions of TSP in megacities of India, 1990 (tonnes per annum)	
City	SPM
Delhi	116,000
Mumbai	50,000
Kolkata	200,000

megacities of India are provided in Table 1.1, which reveals that TSP emissions in Kolkata are the highest followed by Delhi and Mumbai (Sharma *et al.*, 1996). In recent years, the aerodynamic size of suspended particulates has gained more attention as various ailments to the respiratory tract and lungs were found to depend on it.

The aspects of TSP loadings, aerodynamic particle size and its distribution in ambient air, morphology, relationship with pollution sources, health impacts, chemical composition, etc. are discussed in detail in the subsequent chapters.

1.2.2 Toxic elements

The growing need for energy and raw materials to feed a metal-based technology has added large quantities of normally unavailable trace elements in the atmosphere. This sudden availability of trace elements in the atmosphere coupled with their toxicity to the living organisms is the genesis of the problem of trace elemental pollution. Several elements of interest are found in the atmosphere in ultratrace and trace amounts in the form of aerosol. The more important among these are Lead (Pb), Nickel (Ni), Cadmium (Cd), Copper (Cu), Chromium (Cr), Zinc (Zn), Iron (Fe), Manganese (Mn) and Cobalt (Co).

Pb is naturally available in all environmental media in addition to its highly concentrated ores. Natural atmospheric Pb concentration is estimated to be in the range of $0.00005 \mu\text{gm}^{-3}$. Mining, smelting and processing of Pb and Pb containing metal ores, combustion of Pb containing wastes and fossil fuel in incinerators, power plants and industries are important sources of Pb in the atmosphere.

Extensive use of alkyl lead as fuel additive makes vehicular traffic the largest source of Pb, accounting for about 90%, into the atmosphere. High concentration of Pb in urban air has been attributed to vehicular emissions in various countries. Urban concentrations are around $0.5 \mu\text{gm}^{-3}$ and annual average concentrations may reach up to $3.0 \mu\text{gm}^{-3}$ or more in cities with heavy traffic (WHO, 1987). With the introduction of Pb free petrol (0.013 g/l) in India since April 2000, ambient Pb concentrations are expected to come down. Pb is a highly toxic element. It affects several organs of the human body including the nervous system, the blood forming system, the kidneys, the cardiovascular system and the reproductive system. Of most concern are the adverse effects of Pb on the nervous system of young children reducing intelligence and causing attention deficit, hyper activity and behavioral abnormalities. These effects occur at relatively low blood Pb levels without a known threshold (Schwartz, 1994). It has now been well established that increased blood pressure and hypertension in adults are also related to elevated blood Pb levels (Hu, 1996; Kim, 1996; Schwartz, 1994), even at lower levels of exposure, increasing the risk of cardiovascular diseases (Pirkle, 1985).

Ni compounds are used for plating, ceramics coloring, and making certain batteries. Ni is required to maintain health in animals and a small amount is perhaps essential for humans but higher concentration is injurious to health. It causes skin rash, asthmatic attacks, stomach aches and affects blood and kidneys. Ni and some of its compounds are carcinogens causing lung and sinus cancer (ATSDR, 1997).

Cd occurs in association with zinc ores and to lesser extent with lead and

copper ores. It is emitted into the atmosphere by waste incineration, fossil fuel combustion, production of Ni-Cd batteries, cement manufacture and zinc ore processing activities. Atmospheric Cd levels in urban areas range from 0.005-0.015 μgm^{-3} and up to 0.06 μgm^{-3} in industrial areas (WHO, 1972). Cd can cause acute respiratory effects at 1.0 mgm^{-3} concentration and higher concentration may lead to Cd poisoning. Long-term exposure to lower levels of Cd causes kidney disease.

Cu is essential in trace amounts and is involved in number of enzymes like phenol oxydases, cytochrome oxydases etc. High Cu concentration in the atmosphere causes hemolysis.

Cr occurs naturally in rocks, soils and volcanic dust and gases. Cr has three main forms - Cr (0), Cr (III) and Cr (VI). Cr (0) does not occur naturally and Cr (VI) occurs only rarely. Cr (III) is an essential nutrient in our diet in a very small amount. Cr is used for making steel and other alloys, bricks in furnaces, dyes and pigments, chrome plating, leather tanning and wood preserving. All forms of Cr can be toxic at high concentrations but Cr (VI) is more toxic than Cr (III). Long-term exposures to high or moderate levels of Cr (VI) cause damage to nose and lungs and increase risk of non-cancer diseases of lung. Ingestion of high amount of Cr can cause stomach upsets and ulcers, convulsions, kidney and liver damage and even death (ATSDR, 1993).

Zn is one of the most common elements in the earth's crust. It is used as coatings to prevent rust in dry cell batteries and mixed with other metals to make alloys like brass and bronze. Zn in the atmosphere comes from mining activities, steel production, coal burning and waste burning. Zn is an essential element in our

diet. Too little Zn can cause health problems but too much is also harmful. Breathing large amounts of Zn can cause a specific short-term disease called metal fume fever. It may also cause skin irritation.

Fe is one of the most common elements. It is highly reactive and as such available in ore forms. Fe is an essential element required in small amounts for hemoglobin. Very high concentrations are supposed to cause benign pneumoconiosis. It has synergistic effects with SO₂. Higher concentrations inhibit enzyme activities.

Mn occurs naturally and is ubiquitous in the earth's crust, with the composition of surface soils ranging from less than 1 ppm to more than 7000 ppm. It is used as an automotive performance enhancer in the form of methylcyclopentadienyl manganese tricarbonyl (MMT), a manganese based petrol additive (Pellizzari *et al.*, 1999). Mn is emitted in the atmosphere by vehicular emissions, combustion of coal, dry cell battery manufacturing, metalworking and to a lesser extent by burning of plant materials. Mn is an essential element for humans in trace quantities but higher concentration leads to various diseases and poisoning.

Co is used for making alloys, colored pigments and as a drier for paint and porcelain enamel used on steel fixtures, large appliances and kitchenwares. It is emitted in the atmosphere by combustion of coal and oil. Co has both beneficial and harmful effects on human health. It is a part of vitamin B12 and is also used for treatment of anemia because it induces red blood cell production. High-level exposure to Co affects lungs causing pneumonia and wheezing.

1.3 POLLUTION CONTROL LAWS AND THEIR OBJECTIVES

The objectives of the pollution control laws are to prevent and control the discharge of pollutants into the air, which can harm human health and natural resources. It regulates pollution by establishing ambient air quality standards at which pollutants can be safely tolerated. It also regulates emission sources through a system of limitations on specified pollutants and a permit programme for major sources.

In India, the Air (Prevention and Control of Pollution) Act, 1981 has been enacted with the objective to prevent and control air pollution problems. The Act became applicable in the whole country in 1981 itself by the provisions contained therein. Under the Act, the Central and State Pollution Control Boards are entrusted with the task to implement its various provisions. Subsequently, Environment (Protection) Act, 1986 has been implemented in the country to deal with the problems not covered under the Air Act. At present, India is among the few of the countries in the world having comprehensive pollution control Acts and Rules.

1.4 AIR QUALITY MONITORING

Methodical and accurate documentation of air quality is of prime importance to establish ambient pollution levels, ascertain human exposure, assess the contribution from different air pollution sources and to appraise the effects of control measures including compliance with existing air quality standards (WHO, 1969). Further, it can assess the effects of specific human activities on the environment and facilitate evolution of exact strategies to control pollution.

International efforts to monitor the ambient air quality worldwide are summarized by the World Health Organisation (WHO, 1984). The United Nations Environment Programme (UNEP) with the support and cooperation of 33 intergovernmental agencies and at 136 sites was launched in 1973 for the development of Global Environmental Monitoring System (GEMS) with the objective to assess air pollution on global scale, to observe trends and to begin the examination of the relationship between pollution and human health. The study was limited to two ubiquitous pollutants namely SPM and SO₂. Presently, almost all the developed and most of the developing countries have their own national air quality monitoring networks to study their air pollution problems.

During the past few decades, a large amount of work has been carried out to assess the atmospheric pollution due to particulates and trace elements in different kinds of atmosphere. The aerodynamic particle size characteristics were assessed at urban (Harrison *et al.*, 1999), rural and alpine (Monn *et al.*, 1999), street level and rooftop (Väkevä. *et al.*, 1999) and valley (Chow *et al.*, 1992) sites. The studies on particulate morphology (Zou, 1997) and its properties (Fassi-Fihri *et al.*, 1997) provide vital information. The data indicate that particle number density is a better indicator of pollution source than particulate mass. The studies on characteristics of biological particulates and statistical analysis of various parameters establish interrelationships. Several researchers have also studied the change in vertical profiles of particulates and role of meteorological factors.

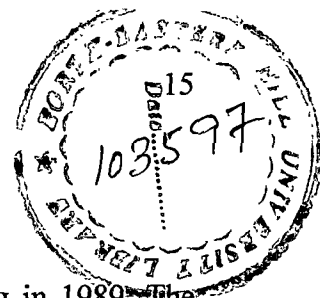
Substantial work has also been carried out to assess the air pollution loads due to release of trace elements in developed countries and in different atmosphere

like near seacoast (Kretzschmar *et al.*, 1979), urban, suburban and rural (Molnár *et al.*, 1993), gulf countries (Foner *et al.*, 1992) and African countries (Eltayeb *et al.*, 1993). In addition, studies were carried out to understand the impact of the introduction of unleaded petrol (Simmons *et al.*, 1993) and at specific conditions like oil fire conditions (Raveendran *et al.*, 1992). The levels of elements measured in these studies serve as an index of the extent of pollution. Studies also point out that the behaviour of trace elements in the atmosphere depends on their chemical nature and size distributions and explain that these two characteristics are mostly dependent on the sources and meteorological conditions. The study of elemental constituents as a function of particle size is made to understand their effects on health and environment (Khandekar *et al.*, 1980). Methods of examining the relative importance of sources on the measured trace element concentrations to compare the relative abundance in source materials to that found in atmosphere i.e. enrichment factor analysis were also widely used. The enrichment factor is calculated by obtaining the ratio of the concentration of an element in air particulate matter normalized to a reference element. Paoletti *et al.* (1999) have applied this method to characterize the individual particles in a controlled underground area. Several workers have calculated the linear correlation coefficients for all possible element pairs to see the interrelationship that exists among various elements. It is observed that highly correlated species may come from the same primary source or secondary transformation process or that the species are carried together in the same air mass. Identification of air pollution

sources has usually been done either by method of chemical mass balance (CMB) or by statistical method like factor analysis (Hopke, 1981). Application of CMB needs specific knowledge of elemental emissions from various sources. Factor analysis is widely used by many researchers for source apportionment of pollutants. It is a reliable statistical tool to obtain information about the possible sources of pollution that differentiates the separate patterns of relationships in the matrix of correlation coefficients by factoring the matrix into its basic dimensions and condensing large data sets into uncorrelated sets of factors, which corresponds to different sources of pollution.

1.5 AIR POLLUTION MONITORING AND STUDIES IN INDIA

India is a leading developing country and presently falls among the ten most industrialized nations of the world. Pollution monitoring and control throughout the country is a gigantic task as there are about 300 cities and 3696 towns with populations of 1 lakh or above as per the 1991 Census of the Government of India. The Central Pollution Control Board (CPCB), Delhi has commenced NAMP in 1984-85 with 7 stations. Subsequently, the number of monitoring stations under the programme increased to 290 by 1992 covering 24 states and 5 union territories. The specific pollutants monitored from these stations are SPM, SO₂ and NO_x. Recently, particle with aerodynamic size below 10 µm (PM₁₀) has also been added in the list of the monitored parameters. Lead is monitored only at few selected locations and benzene and poly aromatic hydrocarbons (PAH's) at national capital Delhi.



Under the NAMP, two stations were established in Shillong in 1989. The stations are located at Lumpyngngad (a hill top located away from vehicular movements) and at Police Bazar (city centre and main commercial activity area). While the Lumpyngngad monitoring station is located at ground level, Police Bazar monitoring station is located on the rooftop of a building at an approximate elevation of about 10 meters. Some criteria pollutants like SPM, SO₂ and NO_x are monitored from these two stations.

The awareness about the prevailing pollution problems in the country is quite high. It is evident from the large number of institutions and research groups working in this field since the last few decades. The studies conducted at Mumbai (Sharma *et al.*, 1992; Tripathi *et al.*, 1993), Varanasi (Pandey *et al.*, 1992; Tripathi *et al.*, 1995), Kolkata (Mandal, 1999), Kanpur (Joshi, 1981) and industrial and mining areas (Sahu *et al.*, 1997) provide extent of pollution levels in these areas. One common feature of these studies is that the elevated TSP levels were obtained at most of the studied areas. The particle size resolved elemental concentrations were studied at Mumbai and Varanasi.

The literature survey reveals that particle size distribution data for urban atmosphere is very scanty with hardly any work in the north-eastern region of India. No study could be found that provides details about particle size distributions and chemical compositions with respect to soot and elements specially at breathing level of the population.

1.6 AIR QUALITY STANDARDS

Air quality standards are health-based standards used to measure and protect the air around us. The basic objective of such standards is to protect the public from adverse health effects. These represent the lowest level at which available evidence suggests that an effect will be produced within a reasonable margin. In other words, air quality standards are a legal limit under which a certain level of pollutant is allowed to discharge. The air quality standards are evolved considering exposure conditions, importance of health related problems and socio-economic conditions. As such, different countries have generally adopted different air quality standards. In India, the National Ambient Air Quality Standards (NAAQS) were first adopted in 1982. Subsequently, the NAAQS were revised in 1994. The Indian NAAQS are based on land use and certain other important factors (Table 1.2).

Table 1.2 Classification of land use under NAAQS in India		
1.	Industrial Areas	Areas with intensive industrial activities
2.	Residential, Rural and Mixed Use Areas	Areas not covered in (1) and (3) categories
3.	Sensitive Areas	Hill stations, tourists resorts, hospitals, national parks, national monuments, health resorts and sanctuaries

The Indian NAAQS, WHO standards, USEPA standards, United Kingdom AQS and Japan AQS are given in Table 1.3.

Table 1.3 Ambient air quality standards of India, WHO and other countries ($\mu\text{g}/\text{m}^3$), CPCB, 2000								
Air Pollutant	Time weighted average	WHO, 1999	India, 1994			USEPA, 1997	UK, 1997	Japan
			Industrial	Residential	Sensitive			
Oxides of Nitrogen (NO_x)	Annual average	40	80	60	15	100	21 ppb	-
	24 hours	-	120	80	30	-	-	75-113
	1 hour	200	-	-	-	-	150ppb	-
Sulfur dioxide (SO_2)	Annual average	50	80	60	15	80	-	-
	24 hours	125	120	80	30	365	-	-
	3 hour	-	-	-	-	1300	-	-
	1 hour	-	-	-	-	-	100ppb	286
	10 min	500	-	-	-	-	(15min)	-
Carbon monoxide (CO)	8hours	10,000	5000	2000	1000	10,000	10ppm	-
	1 hour	30,000	10,000	4000	2000	40,000	-	22900
	30 min	60,000	-	-	-	-	-	-
	10 min	100,000	-	-	-	-	-	-
		0	-	-	-	-	-	-
Lead (Pb)	Annual average	0.5	1.0	0.75	0.50	1.5	0.5	-
	24 hours	-	1.5	1.0	0.75	-	-	-
RSPM: PM_{10}	Annual average	-	120	60	50	50	-	-
	24 hours	-	150	100	75	150	50	100
SPM	Annual average	*	360	140	70	-	-	-
	24 hours	*	500	200	100	-	-	-
$\text{PM}_{2.5}$	Annual average	-	-	-	-	15	-	-
	24 hours	-	-	-	-	65	-	-
Ozone (O_3)	8 hours	120	-	-	-	157	50ppb	120
	24 hour	-	-	-	-	235	-	-
Ammonia (NH_3)	Annual average	-	-	100	-	-	-	-
	24 hours	-	-	400	-	-	-	-

* No definite guidelines mentioned

1.7 MOTIVATION BEHIND THE PRESENT WORK

The CPCB guidelines define the siting criteria for particular air pollution monitoring station for assessment of criteria pollutants including TSP under NAMP. These stations are located either at ground level or up to 15-meter elevation depending upon the availability of a suitable location. The air pollution status statistics of NAMP do not provide information about the particular elevation of the

sampling stations. When we consider the urban air pollution profile of a city, it becomes evident that pollutants predominantly come from one specific source i.e. vehicular exhaust emissions released at the breathing zone of the people. As such, it is more important to assess the pollution levels at breathing level to measure the pollution loads, which adversely affects human health.

Soot (elemental carbon) is an important constituent of TSP, which is used to determine the pollution levels and sources in many of the developed nations. Fine soot particles are associated with health and amenity problems and some European countries have already set standards for this pollutant. In India, the work on ambient soot concentration aspects also requires to be attempted.

Determination of the concentration of oil-drops in suspended particulates is of significant interest particularly in areas of high vehicular density and dense pine forests as the latter emanate natural terpenes in the form of oil-drops.

In recent years, the aerodynamic size of suspended particulates has gained immense significance as various ailments of the respiratory tract and lungs are found to be associated with it. A number of time-based studies have linked different levels of PM_{10} with increased incidences and durations of respiratory symptoms, increased hospitalization for respiratory diseases, increased lung dysfunction and increased cardio-pulmonary mortality. It is now also established that the number of fine particles below $2.5\ \mu m$ ($PM_{2.5}$) are most important from the human health perspective as they are able to penetrate further into the respiratory system and have much longer residence time in the atmosphere compared to the coarser particles. Epidemiological evidence also suggests that there may be no safe threshold limits

for fine particulates and that the health effects are linearly related to its concentration.

The importance of assessing concentration of toxic trace elements in air particulates has been well accepted due to its health reasons. The most significant among these are Pb, Ni, Cu, Cd, Cr, Fe, Zn, Mn, and Co. Few major elements like Na, K and Mg are also important as they help in the identification of their loading sources.

Until recently, only TSP based Indian NAAQS was used in India. These mass based standards for respirable suspended particulate matter (RSPM: PM_{10}) were introduced in the country only in the nineties (CPCB, 2000). The equipment recommended for RSPM monitoring was the respirable dust sampler: an improvised high-volume gravimetric sampler fitted with a cyclone as PM_{10} cut-off device. This sampler is perhaps recommended since it is economical and readily available though the knowledge about the efficiency of the PM_{10} cut-off device of this equipment is quite limited. So far, no standards with respect to soot and $PM_{2.5}$ have been set in the country despite the fact that the vehicular pollution in the urban atmosphere is of growing concern in India. Moreover, it is increasingly realized that the mass based standards hardly provide the true particulate size distribution characteristics and their associated health implications because the finer particles though very high in number account less for mass in comparison with the coarser particles, as such, making it important to study the particulate profiles and their number concentrations.

There is an unambiguous dearth of systematic works to understand urban air

pollution profile on breathing level TSP loadings and soot concentrations, particle size distributions, and elemental compositions in the north-eastern region particularly Shillong. These aspects do not appear to have been covered by the researchers even for the country as well.

Shillong is a hill station and, as such, its climate is temperate in nature. It also records high rainfall and its rainy season extends from mid May to October with intermittent rainfall for almost throughout the year. These highly humid and cold climatic conditions are quite different from the rest of the country. Air pollution statistics for such urban atmosphere in India are hardly available. Moreover, the temperate climate of Shillong also acts as a virtual trap for air pollutants facilitating its large build up in the atmosphere that invariably require detailed studies to understand atmospheric pollution characteristics.

To fill these gaps, the present study was undertaken to assess the air quality of Shillong with respect to TSP and soot loadings, aerodynamic particle size distributions and concentration of toxic trace and major elements at breathing level. In addition, traffic density patterns and meteorological characteristics were planned to be recorded throughout the sampling durations to obtain their interrelationships with the monitored concomitants. The objectives of the study also included Receptor Modeling for source apportionment of solid particles and toxic trace and major elements using Principal Component Analysis technique. Particle size distribution analysis with Image Analysis System, morphology of solid particles with Scanning Electron Microscope, enrichment factors analysis of monitored elements to obtain their possible sources in aerosols and correlation analysis of

elements to understand their sources and transport behaviour in the atmosphere were also the part of the scope of the study.

The present work is summarized in 6 (six) Chapters. The planning, survey and experimental details are described in Chapter 2. Chapter 3 comprises of details regarding determination of mass loadings of TSP and soot at breathing level, oil-drop concentrations, relationship of TSP and soot with traffic density and meteorological variables, cluster analysis and category-wise representation of TSP in Shillong and relationship of soot with TSP. Determination of aerodynamic size and distribution patterns of solid particles, relationship with traffic density, meteorological factors and source apportionment of solid particles by Principal Component Analysis technique, aerodynamic size distribution of oil-drops and relationship with traffic density, comparison of particle size distribution data obtained with optical microscope and Image Analysis System and determination of particulate morphology with Scanning Electron Microscope are discussed in Chapter 4. Chapter 5 includes the aspects of determination of the concentration of different elements, Enrichment factor analysis of elements, correlation analysis of elements and source apportionment of elements using Principal Component Analysis. The summary of the results of the present study and future perspectives of work constitutes Chapter 6.

It is envisaged that the present study will help in understanding the TSP and soot concentrations and its likely sources, particle size distributions, particulate morphology and elemental concentration profiles at breathing level of Shillong. The outcome of the study may also facilitate formulation of action plans for curbing the

problem of prevailing air pollution and in planning strategies for future urban development/management programmes of city. It is also believed that the study may act as an impetus for carrying out of similar studies in other parts of the north-eastern region as well as in the country, which in turn will provide the necessary data to map the areas with potential health risks. It may perhaps be also of use for evolving criteria for soot and $PM_{2.5}$ concentrations in the country.

CHAPTER 2

CHAPTER 2

PLANNING, SURVEY AND EXPERIMENTAL DETAILS

2.1 THE STUDY AREA- AN OVERVIEW

The study area covers the city of Shillong, headquarter of East Khasi Hills district and the capital of the state of Meghalaya, India. It is positioned at Latitude 25° 35' N and Longitude 91° 53' E. Commonly known as the "*Scotland of the East*", it is one of the most picturesque and beautiful hill stations famous for its scenic beauty of natural pine forests and cascading waterfalls. Situated on the Khasi Hills range at the varying altitudes of 1400 to 1950 meters above mean sea level, Shillong is one of the biggest hill stations of India.

Over a century, the tiny hamlet of Shillong has overgrown to a thriving city functionally changing from a hill resort to a multi functional entity acting not only as an administrative-cum-tourist centre but also as a regional educational and commercial centre of the entire north-eastern region.

The Master Plan of Shillong, 1991-2011 covers an area of 70.4 km² (Master Plan of Shillong, 1991). It defines the land resources of the city into five broad categories of developed, underdeveloped, developable, urban agriculture and forests

Table 2.1 Land resources of Shillong		
Category	Area Covered (km²)	% of Total Area
Developed Area	25.4	36.1
Underdeveloped Area	6.4	9.1
Developable Area	17.4	24.7
Urban Agriculture	3.2	4.5
Forests and Water Bodies	18.0	25.6

& water bodies. The geographical area covered under each category is given in Table 2.1. The developed area or Shillong agglomeration consists of Madanrting, Mawlai, Nongthymmai, Pynthorumkhrah, Shillong Cantonment and Shillong Municipality urban centres. The major residential, commercial, educational, recreational, industrial areas, highways, road network and elevations are shown in Fig. 2.1.

The population of Shillong has grown steadily since 1901. The population growth of the city is provided in Fig. 2.2. The estimated population of Shillong in

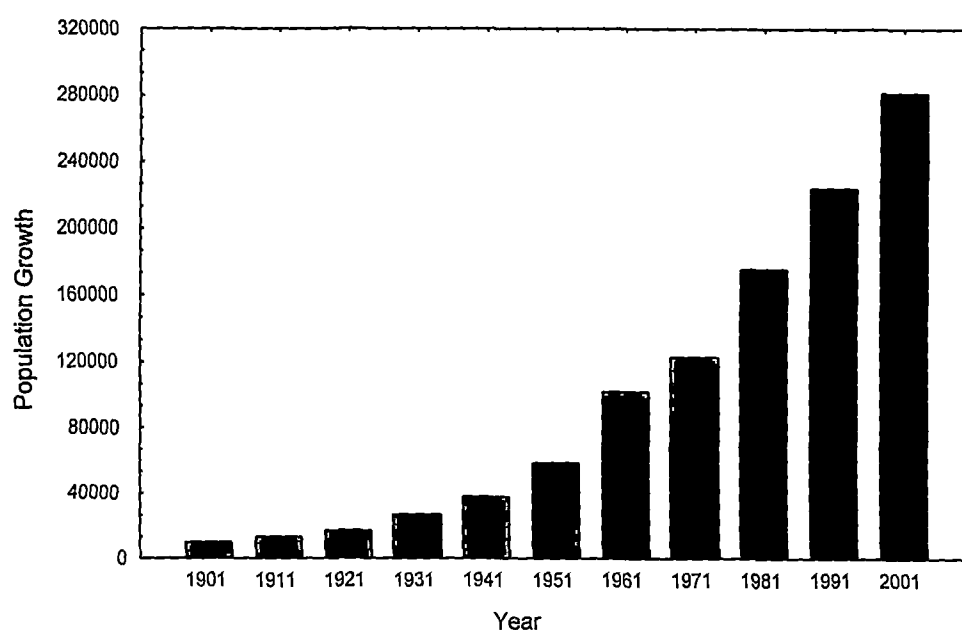


Fig. 2.2 Population growth in Shillong

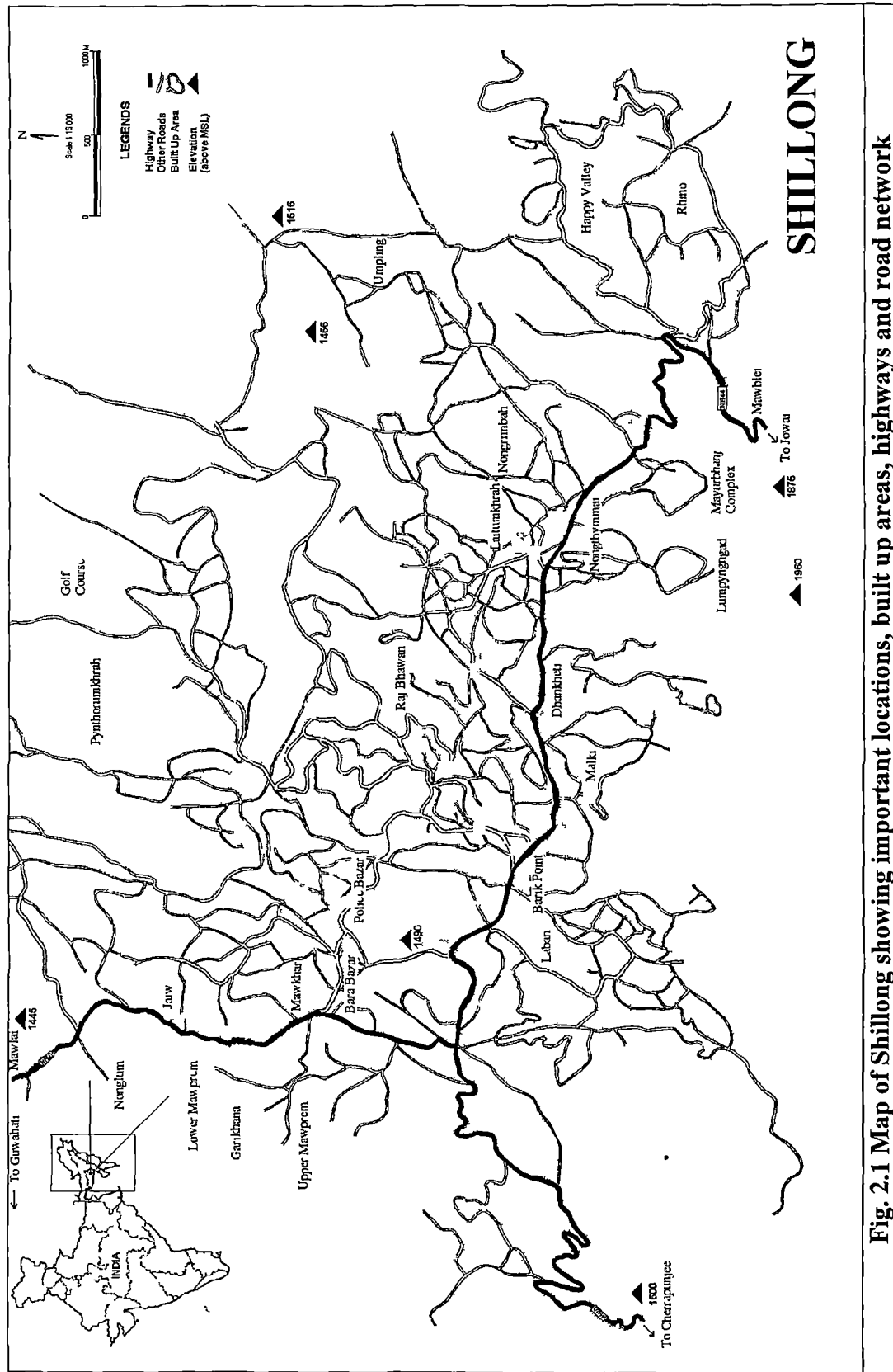


Fig. 2.1 Map of Shillong showing important locations, built up areas, highways and road network

2001 is 2,81,246. This shows an increase of about 29 times in comparison with the 1901 population. The area covered under industrial use is 0.04 km², which is about 0.06% of the total master plan area. This clearly indicates that industrial development in Shillong is quite minimal. There is one industrial estate at Mawroh where some industries are located in a scattered manner. The industrial units at this industrial estate are small scale and are mostly of non-polluting in nature. Restaurants, hotels, domestic fuel burning, space heating during winters and a few flourmills are the air pollution activities in Shillong besides vehicular exhaust emissions, which are considered as the major source.

2.2. SAMPLING PLAN FOR BREATHING LEVEL AIR QUALITY

For the purpose of total suspended particulate (TSP) sampling to study the pollution loads, particulate size distribution characteristics, soot concentrations and elemental composition in Shillong, the first task was to judiciously select the sampling locations in the city that may not only provide representative samples but also reflect overall pollution patterns. Some broad guidelines are available for the purpose (Morgan *et al.*, 1971). To achieve the objective of the assessment of breathing level air quality in Shillong, the concept of spatial representation seemed to be an appropriate option as it provides a useful basis for classifying locations and the uses to which the data are put. Furthermore, the concept has a physical basis that can serve to provide true station characteristics. The fixed site monitoring from single station is often influenced by nearby sources that may not represent the exposure of the community at large (Chow, 1995). Moreover, the varying urban

conditions cannot be specified with a single station. Siting criteria adopted in this study were such that the exposure of population to pollutants would provide realistic representation.

As mentioned earlier, the main source of air pollution in Shillong is vehicular exhaust emissions. As such, we selected sampling locations at the control sites (away from vehicular movements), NH 40 & 44 (within the city confines), major roads, educational and commercial clusters, busy traffic intersections, highways and indoor environment, industrial estates/areas and at various elevations to have an overall assessment of the city and to evaluate the community exposure at various situations. All the samples (excluding those at various elevations) were collected at 1.0 meter distance from the road and at 1.5 meter elevation from the ground level (breathing level). A total of 84 locations were selected for the purpose. The sampling was performed twice for all the selected sampling locations during dry periods (November to mid May) of 1997-98 and 1998-99. One additional sampling for 23 locations was performed during Oct-Nov, 1998. The various selected sampling locations in Shillong are shown in Fig. 2.3 and the details regarding criterion for selection of sampling locations and location environment are provided hereunder.

2.2.1. Control locations

Three stations of different topographic characteristics and away from any vehicular movements were selected as control locations (CB). All three locations were basically small residential pockets surrounded by pine forests. The site-specific characteristics of the CB locations are provided in Table 2.2.

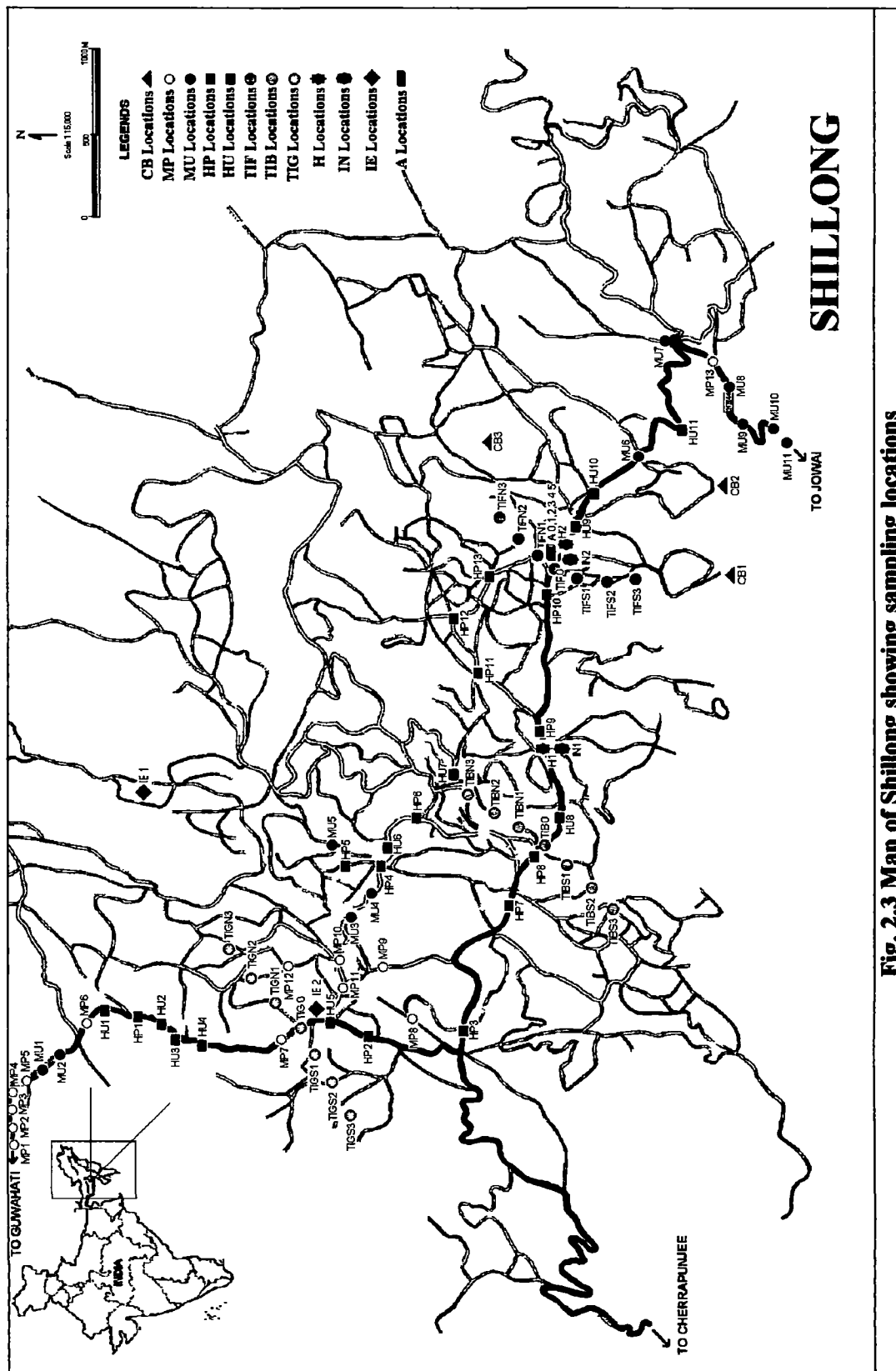


Fig. 2.3 Map of Shillong showing sampling locations

Table 2.2 Site specific characteristics of CB locations				
S No	Sampling Location	Location Code	Land Use	Location Environment
1	Lumpynggad	CB1	Residential	Hill top with medium population density, surrounded by pine forests,
2	Nongrim Bah	CB2	Residential	Valley with medium population density, surrounded by pine forests
3	Mayurbhanj	CB3	Residential/ Educational	Hillocks with medium population density, educational institutions, surrounded by pine forests

2.2.2 Locations on national highways, major roads, commercial and educational clusters

In all, 48 sampling locations were selected on the criterion to cover NH 40 and NH 44 within the city limits, major city roads and busy commercial and educational establishments. The locations were selected from Check Gate, Mawiong (the entrance point of the city in the east) up to Mawblei (the extreme end point of city in the west). The sampling locations were selected in such a manner so as to cover all-important residential, commercial, administrative, educational and recreational zones of the city. Due to the highly undulating hilly terrain of Shillong, the selected sampling locations were divided into the categories of plain roads (roads with level stretches denoted by 'P') and uphill roads (roads with steep gradients denoted by 'U') purely on visual basis. The vehicular traffic density at these 48 stations was also monitored on hourly basis (described in section 2.3) and was categorized as moderate (total traffic density, $\rho_T < 500$ vehicles/h denoted by 'M') and high (total traffic density, $\rho_T > 500$ vehicles/h denoted by 'H'). On the basis of the road gradients and traffic density, the 48 sampling locations were divided into four categories of MP locations (moderate traffic density with comparatively flat roads), MU locations (moderate traffic density with high gradient roads), HP

locations (high traffic density with comparatively flat roads) and HU locations (high traffic density with high gradient roads).

There are 13 locations falling under MP category. These locations contain purely residential, residential-cum-commercial and dedicated commercial areas. Most of the locations are situated along the highways and a few on major road links. The site-specific characteristics of MP locations are provided in Table 2.3.

The MU category contains 11 locations. These locations are situated at steep gradients and also include purely residential, residential-cum-commercial and dedicated commercial areas. Excluding 3 commercial locations, which are placed at city centre on major road links, remaining locations are situated along the highways. The site-specific characteristics of MU locations are provided in Table 2.4.

The HP category contains 13 locations. These locations are situated at relatively level stretches and also include secretarial, residential, residential-cum-commercial and dedicated commercial areas. About half of the locations are situated on highways and rest on busy educational and commercial locations. The site-specific characteristics of HP locations are provided in Table 2.5.

There are 11 locations in HU category. These locations are situated at steep gradients and include secretarial, residential and residential-cum-commercial areas. Excluding 2 locations, rests are situated on highways. The site-specific characteristics of HU locations are provided in Table 2.6.

Table 2.3 Site-specific characteristics of MP locations

S No	Sampling Location	Location Code	Land Use	Road Gradient	Location Environment
1	Check Gate, Mawiong	MP1	Highway	Relatively flat	Located on highway, thinly populated, surrounded by pine forests,
2	Forest Check Gate, Mawiong	MP2	Highway/ Residential	Relatively flat	Located on highway, surrounded by pine forests
3	Mawiong	MP3	Highway/ Residential/ Commercial	Relatively flat	Located on both sides of highway, thinly populated, low and medium height buildings, low commercial activities
4	New Market, Mawiong	MP4	Highway/ Residential/ Commercial	Relatively flat	Located on both sides of highway, thinly populated, low and medium height buildings, low commercial activities
5	Old Gate, Mawlai	MP5	Highway	Relatively flat	Located on highway, surrounded by medium height hillocks, hot mix plant of PWD nearby
6	Mawlai Nongkwar (Near Auto Center)	MP6	Highway/ Residential/ Commercial	Relatively flat	Located on both sides of highway, medium populated, low and medium height buildings, low commercial activities
7	Lama Villa, Garikhana	MP7	Highway/ Residential/ Commercial	Relatively flat	Located on both sides of highway, medium populated, high and medium height buildings, low commercial activities
8	21 A Cantonement Area	MP8	Residential/ Commercial	Relatively flat	Located on both sides of major road, high and medium height buildings, city bus station high commercial activities,
9	Iew Mawlong, Barabazar	MP9	Commercial	Relatively flat	Located on both sides of major road, thickly populated, high and medium height buildings, high commercial activities,
10	Main Crossing, Barabazar	MP10	Commercial	Relatively flat	Located on both sides of major road, thickly populated, high and medium height buildings, high commercial activities
11	Jeep Stand, Barabazar	MP11	Commercial	Relatively flat	Located on both sides of major road, thickly populated, high and medium height buildings, high commercial activities
12	Synod Complex, Motphran	MP12	Residential/ Commercial	Relatively flat	Located on both sides of major road, thickly populated, high and medium height buildings, high commercial activities
13	Petrol Pump, Demthring	MP13	Highway/ Residential/ Commercial	Relatively flat	Located on both sides of major road, thickly populated, high and medium height buildings, high commercial activities

Table 2.4 Site-specific characteristics of MU locations

S No	Sampling Location	Location Code	Land Use	Road Gradient	Location Environment
1	Mawlai Umtholong	MU1	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thickly populated, high and medium height buildings medium commercial activities,
2	Mawlai Nongkwar	MU2	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thickly populated, high and medium height buildings medium commercial activities,
3	Arya Samaj Temple, Barabazar	MU3	Commercial	Uphill	Located on both sides of roads, high and medium height buildings, high commercial activities
4	Police Bazar	MU4	Commercial	Uphill	Located on both sides of roads, high and medium height buildings, high commercial activities
5	MTC Bus Stand, Police Bazar	MU5	Commercial	Uphill	Bus stand, high and medium height buildings, medium commercial activities
6	Beat House, Nongthymmai	MU6	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thickly populated, low and medium height buildings, medium commercial activities
7	Sawlad Bus Stand, Upper Nongthymmai	MU7	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thickly populated, low and medium height buildings, medium commercial activities
8	Aloogodam, Madanryting	MU8	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, medium populated, low and medium, height buildings, low commercial activities
9	Lumingsuk, Madanryting	MU9	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, medium populated, low and medium height buildings, low commercial activities
10	Madanryting Mawblei	MU10	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thinly populated, low and medium height buildings, low commercial activities, pine forests around
11	Mawblei	MU11	Highway/ Residential	Uphill	Located on both sides of highway, thinly populated, low height buildings, pine forests around

Table 2.5 Site-specific characteristics of HP locations

S No	Sampling Location	Location Code	Land Use	Road Gradient	Location Environment
1	Jinkiang Mawlai	HP1	Highway/ Residential/ Commercial	Relatively flat	Located on both sides of highway, thickly populated, high and medium height buildings medium commercial activities,
2	Luckier Road, Near Durga Temple	HP2	Highway/ Residential	Relatively flat	Located on both sides of highway, thinly populated, low and medium height buildings
3	Arunachal Secretariat	HP3	Highway/ Residential/ Secretarial	Relatively flat	Highway, thinly populated, low and medium height buildings, secretarial activities
4	Centre Point, Police Bazar	HP4	Commercial	Relatively flat	High and medium height buildings, high commercial activities
5	TB Hospital, Police Bazar	HP5	Commercial	Relatively flat	High and medium height buildings, high commercial activities
6	Shillong Club	HP6	Secretarial/ Commercial	Relatively flat	High and medium height buildings, secretarial activities, medium commercial activities
7	Civil Hospital	HP7	Highway/ Residential	Relatively flat	Highway, medium populated, medium height buildings
8	Barik Point	HP8	Highway/ Residential/ Secretarial	Relatively flat	Highway, medium height buildings, medium populated, secretarial activities
9	Dhankheti	HP9	Highway/ Residential/ Commercial	Relatively flat	Located on both sides of highway, thickly populated, high and medium height buildings, hillock on north direction, medium commercial activities
10	Assam Petrol Pump, Near Fire Brigade	HP10	Highway/ Residential/ Commercial	Relatively flat	Located on highway, medium populated low and medium height buildings, low commercial activities,
11	Don Bosco Square, Laitumkhrach	HP11	Educational/ Residential/ Commercial	Relatively flat	Located on both sides of roads, thickly populated, high and medium height buildings, main educational centre, high commercial activities
12	Police Point, Laitumkhrach	HP12	Residential/ Commercial	Relatively flat	Located on both sides of roads, thickly populated, high and medium height buildings, high commercial activities,
13	Beat House, Laitumkhrach	HP13	Residential/ Commercial	Relatively flat	Located on both sides of roads, thickly populated, high and medium height buildings, high commercial activities

Table 2.6 Site-specific characteristics of HU locations

S No	Sampling Location	Location Code	Land Use	Road Gradient	Location Environment
1	Mawlai	HU1	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thickly populated, high and medium height buildings, medium commercial activities
2	Mawlai, Near SR Construction	HU2	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thickly populated high and medium height buildings, medium commercial activities,
3	Jaiaw	HU3	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thickly populated, high and medium height buildings, low commercial activities,
4	Sunny Hills, GS Road	HU4	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thickly populated, high and medium height buildings, hillock on north-east direction, low commercial activities
5	Luckier Road, Garikhana	HU5	Highway/ Residential	Uphill	Located on both sides of highway, medium populated, low and medium height buildings
6	Meghalaya Legislative Assembly, Police Bazar	HU6	Secretarial	Uphill	Located on north side of highway, high and medium height buildings, high activity zone, secretarial activities
7	IGP Point, Secretariat	HU7	Secretarial	Uphill	High and medium height buildings, high activity zone, secretarial activities
8	Malki	HU8	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, medium populated, low and medium, height buildings, hillock on south direction, low commercial activities
9	Fire Brigade	HU9	Highway/ Residential	Uphill	Located on highway, medium populated, high and medium height buildings, low commercial activities
10	Jinkiang, Nongthymmai	HU10	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, medium populated, low and medium height buildings, low commercial activities
11	Upper Nongthymmai	HU11	Highway/ Residential/ Commercial	Uphill	Located on both sides of highway, thinly populated, low and medium height buildings, low commercial activities

2.2.3 Locations situated across highways on traffic intersections

Three traffic intersections on the NH 40 and NH 44 have been selected to carry out sampling across the national highways. The sites at busy nodes of Fire

Brigade, Barik point and Garikhana are chosen. At one traffic intersection, altogether 7 sampling locations were selected. One location was on the highway and 3 sampling locations each were in the north and south directions across the highways. The distance of the one sampling location from another was approximately 300 meters. As such, a total of 21 traffic intersection locations were selected.

The traffic intersection at Fire Brigade (TIF0) is a residential area with some commercial activities. It is situated on NH 44. The north direction locations are comparatively more populated in comparison with the south direction locations. The extreme south directions (TIFS2 and TIFS3) are located on high gradient terrains. The site-specific characteristics of these locations (TIF) are provided in Table 2.7.

Table 2.7 Site-specific characteristics of TIF locations				
S No	Sampling Location	Location Code	Land Use	Location Environment
1	PNT Quarters, Nongrim Hills (900 M North)	TIFN3	Residential	Residential area, surrounded by pine trees
2	Kumud Villa, (600 M North)	TIFN2	Residential	Residential area, surrounded by pine trees
3	Nagaland House (300 M North)	TIFN1	Residential	Residential area
4	Fire Brigade (On the highway)	TIF0	Highway/ Residential/ Commercial	Located on both sides of highway, medium populated, high and medium height buildings, low commercial activities
5	Lower Motinagar (300 M South)	TIFS1	Residential	Located on low vehicular activity road, residential area, surrounded by pine trees
6	Motinagar (600 M South)	TIFS2	Residential	Located on low vehicular activity road, residential area, surrounded by pine trees
7	Upper Motinagar (900 M South)	TIFS3	Residential	Residential area, surrounded by pine trees

The traffic intersection at Barik Point (TIB0) is situated almost in the middle of the city. It is a residential area with secretarial and some commercial activities. It is also situated on NH 44. The north direction locations are having secretarial activities and a number of government offices are located here. South direction locations contain a famous recreational centre of Lady Hydari park, Pine Mount girl's school and residential colonies. These locations are situated on plain as well as steep gradient terrains. The site-specific characteristics of these locations (TIB) are provided in Table 2.8.

S No	Sampling Location	Location Code	Land Use	Location Environment
1	Behind Governor House, (900 M North)	TIBN3	Residential	Residential area, surrounded by pine trees
2	Lachumiere, (600 M North)	TIBN2	Residential	Residential area, secretarial activities
3	Lower Lachumiere, (300 M North)	TIBN1	Residential	Located on low vehicular activity road, residential area, surrounded by pine trees
4	Barik Point (On the highway)	TIB0	Highway/ Residential/ Commercial	Located on both sides of highway, medium populated, high and medium height buildings, secretarial activities
5	Lady Hydari Park (300 M South)	TIBS1	Recreational	Park with a small zoo, museum and fish ponds, Pine and other trees
6	Pine Mount Girl's School (600 M South)	TIBS2	Residential/ Educational	Residential area, surrounded by pine trees, girl's school
7	Girl's NCC Headquarter (900 M South)	TIBS3	Residential	Residential area, surrounded by pine trees, girl's headquarter

The traffic intersection at Garikhana (TIG0) is located on NH 40 and is near to the busiest commercial centre of the city. Both north and south direction locations are situated on comparatively flat terrains and are either residential or residential cum educational. The site-specific characteristics of these locations (TIG) are provided in Table 2.9.

Table 2.9 Site-specific characteristics of TIG locations				
S No	Sampling Location	Location Code	Land Use	Location Environment
1	Mawkhar (900 M North)	TIGN3	Residential	Residential area, surrounded by pine trees
2	Presbyterian School (600 M North)	TIGN2	Residential/ Educational	Residential area, surrounded by pine trees
3	Narsingh Akhara (300 M North)	TIGN1	Residential	Residential area
4	Garikhana (On the highway)	TIG0	Highway/ Residential/ Commercial	Located on both sides of highway, medium populated, high and medium height buildings, medium commercial activities
5	Upper Mawprem (300 M South)	TIGS1	Residential	Located on low vehicular activity road, residential area, surrounded by pine trees
6	Lower Mawprem (600 M South)	TIGS2	Residential/ Educational	Located on low vehicular activity road, residential area, educational institutions, surrounded by pine trees
7	Dhobitola (900 M South)	TIGS3	Residential	Residential area

2.2.4 Highways and indoor environment locations

Two locations each on highway and indoors were selected for simultaneous sampling to study the variations. Indoor environment locations contain one residential and one commercial location. The site-specific characteristics of these locations (H and IN respectively) are provided in Table 2.10.

Table 2.10 Site-specific characteristics of H and IN locations				
S No	Sampling Location	Location Code	Land Use	Location Environment
1	Jinkieng, Nongthymmai	H1	Highway	Located on both sides of highway, thickly populated, high and medium height buildings, medium commercial activities
2	House, Jinkieng Nongthymmai	IN1	Medium height house	Indoors of residence
3	Dhankheti	H2	Highway	Located on both sides of highway, thickly populated, high and medium height buildings, high commercial activities,
4	Shop, Dhankheti	IN2	Medium height shop	Indoors of Shop

2.2.5 Industrial estates/areas locations

Two locations, one at the industrial estate of Mawroh and the other at an industrial area having flourmill, saw mills etc., have been selected to assess the breathing level air quality of these areas. The Mawroh industrial estate is situated on flat terrain and is surrounded by thick pine forests while the industrial area is located on NH 40 at steep gradients. The site-specific characteristics of these IE locations are provided in Table 2.11.

Table 2.11 Site-specific characteristics of IE locations				
S No	Sampling Location	Location Code	Land Use	Location Environment
1	Mawroh Industrial Estate	IE1	Industrial Estate	High and medium height buildings, small scale non polluting industries, surrounded by pine forests
2	Near Mahabir Flour Mills, Luckier Road	IE2	Residential/ Commercial/ Industrial	Located on highway, medium populated, high and medium height buildings, medium commercial activities, flour and saw mills

2.2.6 Elevation specific locations

The high-rise building of Fire brigade is located on NH 44. It has ideal heights to perform sampling at various elevations. The average heights of buildings in Shillong are smaller than the selected building. The site-specific characteristics of these A locations are provided in Table 2.12.

Table 2.12 Site-specific characteristics of A locations				
S No	Sampling Location	Location Code	Height from Ground Level (M)	Location Environment
1	Ground Floor	A0	1.5	Situated on highway
2	First Floor	A1	5.5	First floor terrace
3	Second Floor	A2	6.8	Second floor terrace
4	Third Floor	A3	10.2	Third floor terrace
5	Fourth Floor	A4	13.6	Fourth floor terrace
6	Rooftop	A5	17.0	Rooftop

2.3 ROAD NETWORK AND TRAFFIC PATTERNS

Shillong is not a planned city. The developmental activities have taken place in a random manner, giving rise to various civic problems. One of the most archetypal problems is insufficient road network. The total road length is 169.1 km occupying 3.2-km² geographical areas, which is 4.5% of the total master plan area and 12.6% of the developed area. As per international standards, about 30% of a city area should be under carpeted roads (CPCB, 1990). As such, the area under roads is quite insufficient. Lack of other modes of transport except roads, restricted road widths, poor geometries of road intersections, lack of parallel corridors, age old traffic management systems, little scope for availability of land for widening of narrow roads, mixing of highways and local traffic due to lack of by-pass road and centralization of various activities are a few problems faced by the city. Highly undulating topography is another handicap in development of the requisite road network. Shillong is not connected with any rail-network from other parts of the country and, as such, road communication is the only mode of available transport. Shillong also acts as a conduit point for the north-eastern states of Mizoram, Tripura and parts of Assam through NH 40 and NH 44 that pass through the city.

The per capita vehicle density of Shillong is quite high as it ranks 4th in the country (almost 1 vehicle amongst 10 persons). The growth in vehicular population in Shillong during 1990-99 is provided in Fig. 2.4. In the absence of any significant development in the industrial sector in the city, vehicular emissions remain as the only major source of air pollution. The number of floating vehicles in Shillong is also considerably high because of its status as a major hill station and conduit point

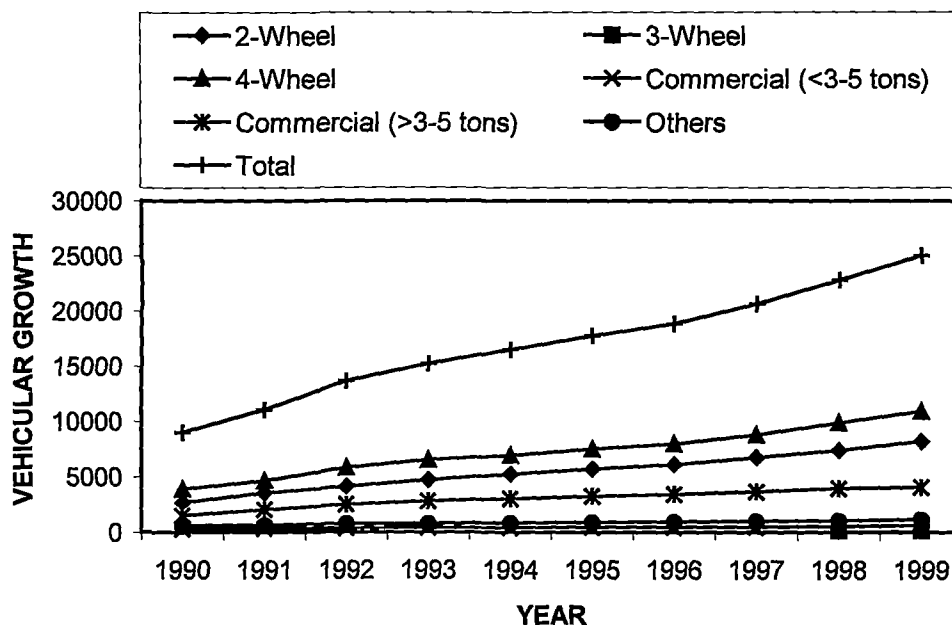


Fig. 2.4 Vehicular growth in Shillong

of north-eastern states.

The nature of vehicular traffic in Shillong is highly heterogeneous and the patterns of diurnal movements in various parts of city are not similar. To assess the vehicular traffic density and changes in the movement patterns of various petrol and diesel driven vehicles, viz., two wheelers (TW) - scooters, motor cycles; light vehicles (LV)- cars, jeeps; heavy vehicles (HV)- buses, trucks etc. manual counting of the vehicles was performed on hourly basis during sampling periods of 9-17 IST. On the basis of traffic density, the selected sampling locations are divided into categories of moderate (total traffic density, $\rho_T < 500$ vehicles/h) and high (total traffic density, $\rho_T > 500$ vehicles/h).

The distinct traffic patterns during sampling hours were observed at MP, MU, HP and HU locations. The average hourly traffic density of TW, LV, HV and ρ_T for MP, MU, HP and HU locations is given in Fig. 2.5 to 2.8 respectively.

At MP locations (Fig. 2.5), the density of TW ranged between 21 to 26 vehicles/h with the peak density at 9-10 IST and 14-15 IST. The LV also showed similar peak hours with the density ranging between 143 to 179 vehicles/h. The HV showed slightly different patterns as the density of these vehicles increased up to 10-11 IST and then again showed peak values at 14-15 IST. The density of HV vehicles

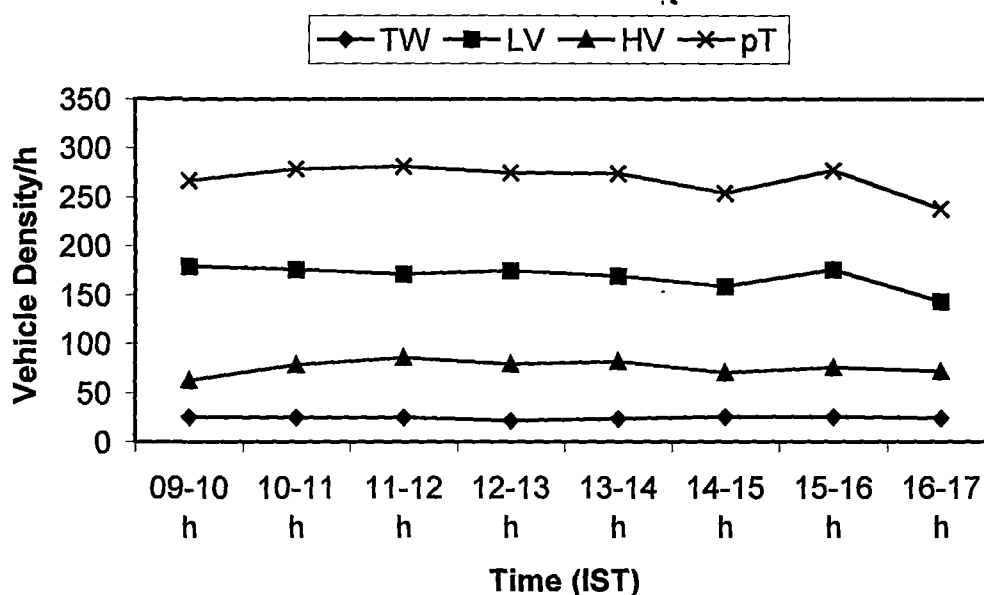


Fig. 2.5 Variations in vehicle density at MP locations

ranged between 62 to 85 vehicles/h. The density of ρ_T ranged from 238 to 281 vehicles/h with peak values at 9 – 11 IST and 14-15 IST.

At MU locations (Fig. 2.6), the average density of TW ranged between 29 to 39 vehicles/h with slight variations during sampling hours. The peak density of TW

was at 10-11 IST, 14-15 IST and 16-17 IST. The LV density ranged between 173 to 199 vehicles/h with peak values at 11-12 IST, 14-15 IST and 16-17 IST. The density of HV was highest during 10-13 IST and then again showed peak values at 16-17 IST. The HV density ranged between 66 to 98 vehicles/h. The density of ρ_T showed similar peak values as of HV. The ρ_T density ranged between 284 to 322 vehicles/h.

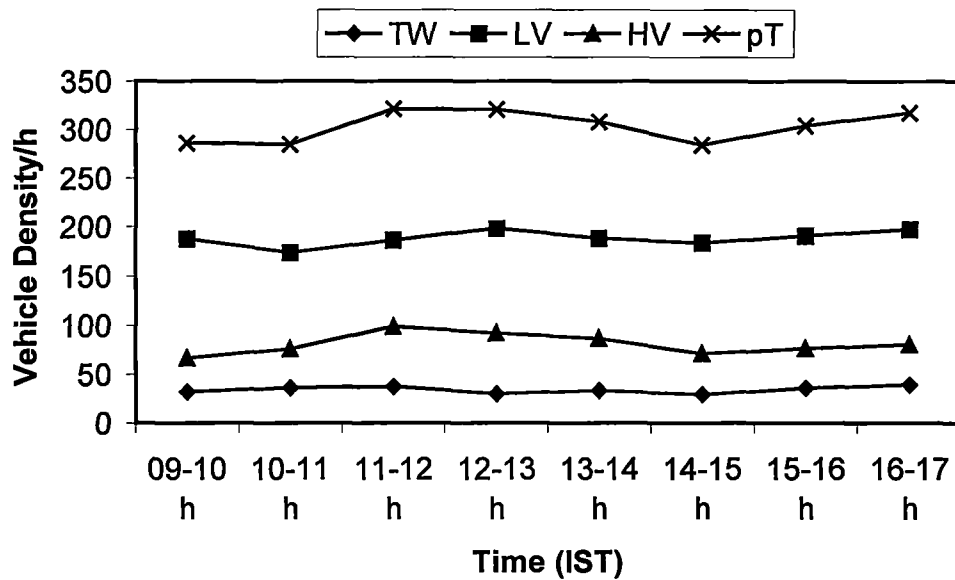


Fig. 2.6 Variations in vehicle density at MU locations

The average density of TW at HP locations (Fig. 2.7) ranged between 116 to 128 vehicles/h with slight variations during sampling hours. The peak density of TW was at 10-12 IST and 14-17 IST. The LV density ranged between 524 to 612 vehicles/h with peak values at 9-10 IST, 13-14 IST and 16-17 IST. The density of HV was highest during 10-13 IST and then again showed peak values at 14-13 IST. The HV density ranged between 76 to 93 vehicles/h. The density of ρ_T showed almost similar peak values as of HV with an additional peak value at 16-17 IST. The

ρ_T density ranged between 717 to 819 vehicles/h.

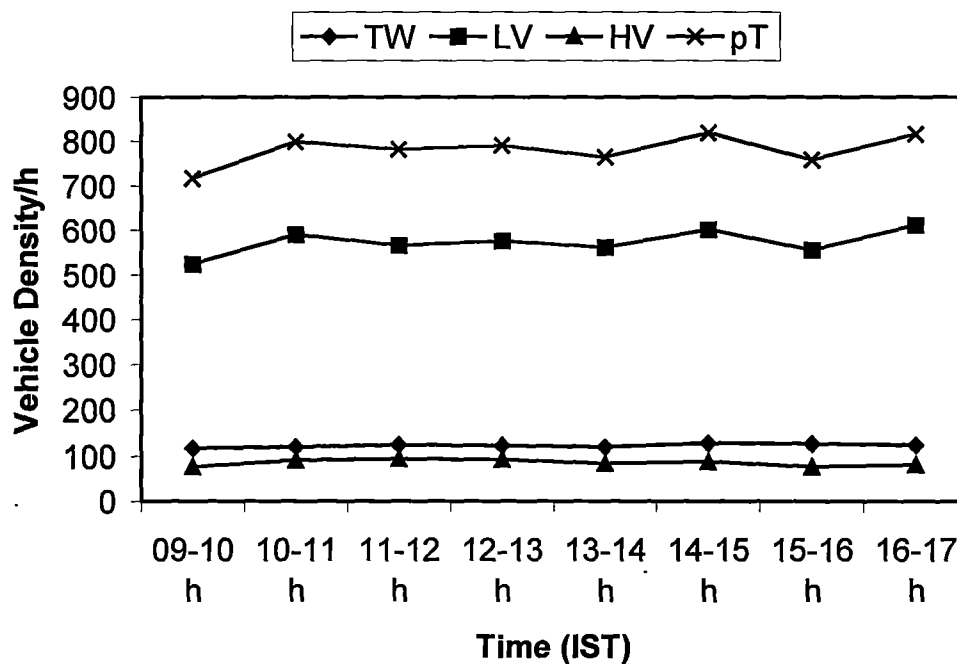


Fig. 2.7 Variations in vehicle density at HP locations

The average density of TW at HU locations (Fig. 2.8) ranged from a mere 11 vehicle/h up to 135 vehicles/h with peak density between 10-12 IST. The LV density ranged between 459 to 546 vehicles/h with peak values between 9-13 IST. The density of HV was highest during 11-14 IST. The HV density ranged between 118 to 165 vehicles/h. The density of ρ_T showed almost similar peak values as of HV only with additional peak values between 14-16 IST. The ρ_T density ranged between 615 to 819 vehicles/h.

The hourly traffic density at MP, MU, HP and HU locations clearly depicted distinct patterns of rush hours. The traffic density was generally high in the morning hours of 9-11 IST. It increased again from 14 IST and showed similar patterns up to

17 IST. The sudden increase in traffic density during morning hours and at around 14 IST was due to the school closing timings and during 10-12 IST and again at 17 IST

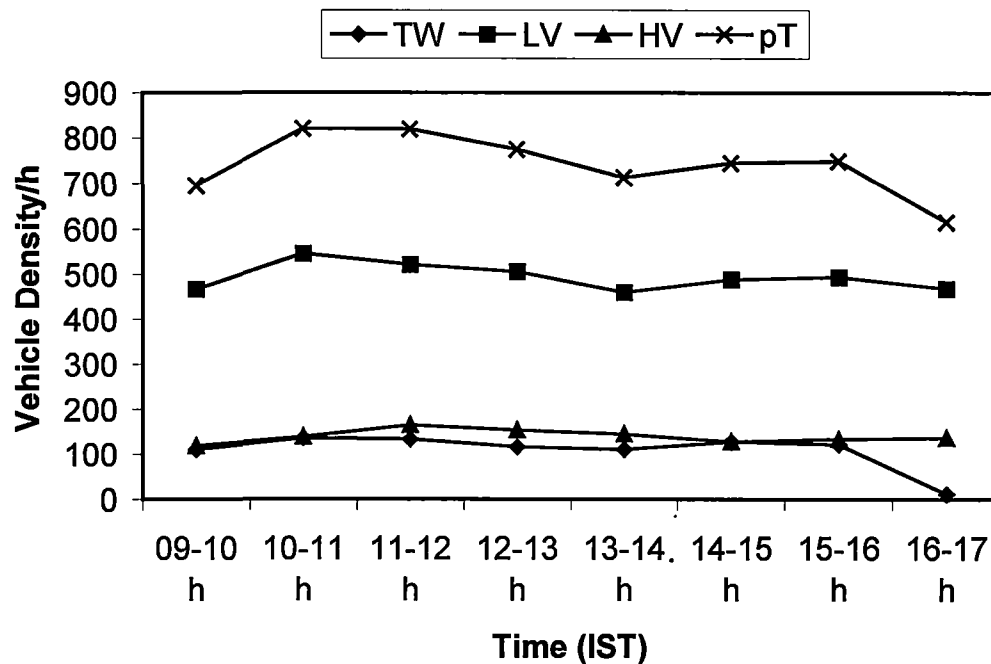


Fig. 2.8 Variations in vehicle density at HU locations

was because of the office rush hours. The HV showed high traffic density from 11 IST up to 16 IST and this appeared to be due to increased commercial activities during these hours.

The total mean traffic density of TW, LV, HV and ρ_T at various categories of sampling locations during the sampling period of 9-17 IST is provided in Appendix-I (Table A.1.1 to A.1.10). In general, LVs are the most utilized vehicles followed by HV. TW is the least utilized vehicles in Shillong.

2.4 THE CLIMATE AND METEOROLOGICAL CONDITIONS

The climate is the study of a region's average daily and seasonal weather

events over a long period. The climate of Shillong, in general, can be considered as temperate in nature. The year can be divided into four distinct seasons of mild summer (March to mid May), rainy season (mid May to mid Oct.), autumn (mid Oct. to Nov.) and winter (Dec. to Feb.). Relatively high temperatures, occasional thunderstorms and high wind velocities characterize the mild summer season. The rainy season commences with the onset of southwest monsoon originating from the Bay of Bengal and Arabian Sea. Shillong experiences a prolonged rainy season with intermittent rain for almost throughout the year, as it is located close to “Cherrapunjee”, the heaviest rainfall receiving area of the World (aerial distance approx 30 km). The short autumn is characterized by sharp decline in temperature. Winter is the coldest season marked with quite low temperatures and considerable cloud/fog covers. The wind rose diagrams showing the diurnal patterns (9-17 IST) during the months of October to May at the fixed weather monitoring station located at Lumpyngngad, Shillong are provided in the Fig. 2.9 and 2.10. The highest calm conditions of 5.9% were observed during the month of December. In the remaining months, the calm conditions ranged from 0.0% to 2.8%. Mostly high wind velocities (7.2-14.4 km/h) and frequent changes in wind directions are the features of these wind rose diagrams.

Meteorology is an important aspect in air pollution studies as pollutants concentrations are inherently dependent on the fluctuations of meteorological variables. It plays a vital role in transport of pollutants from source to receptor, its dispersion in atmosphere and in natural cleansing processes. The most important meteorological factors include ambient temperature, relative humidity, wind speed,

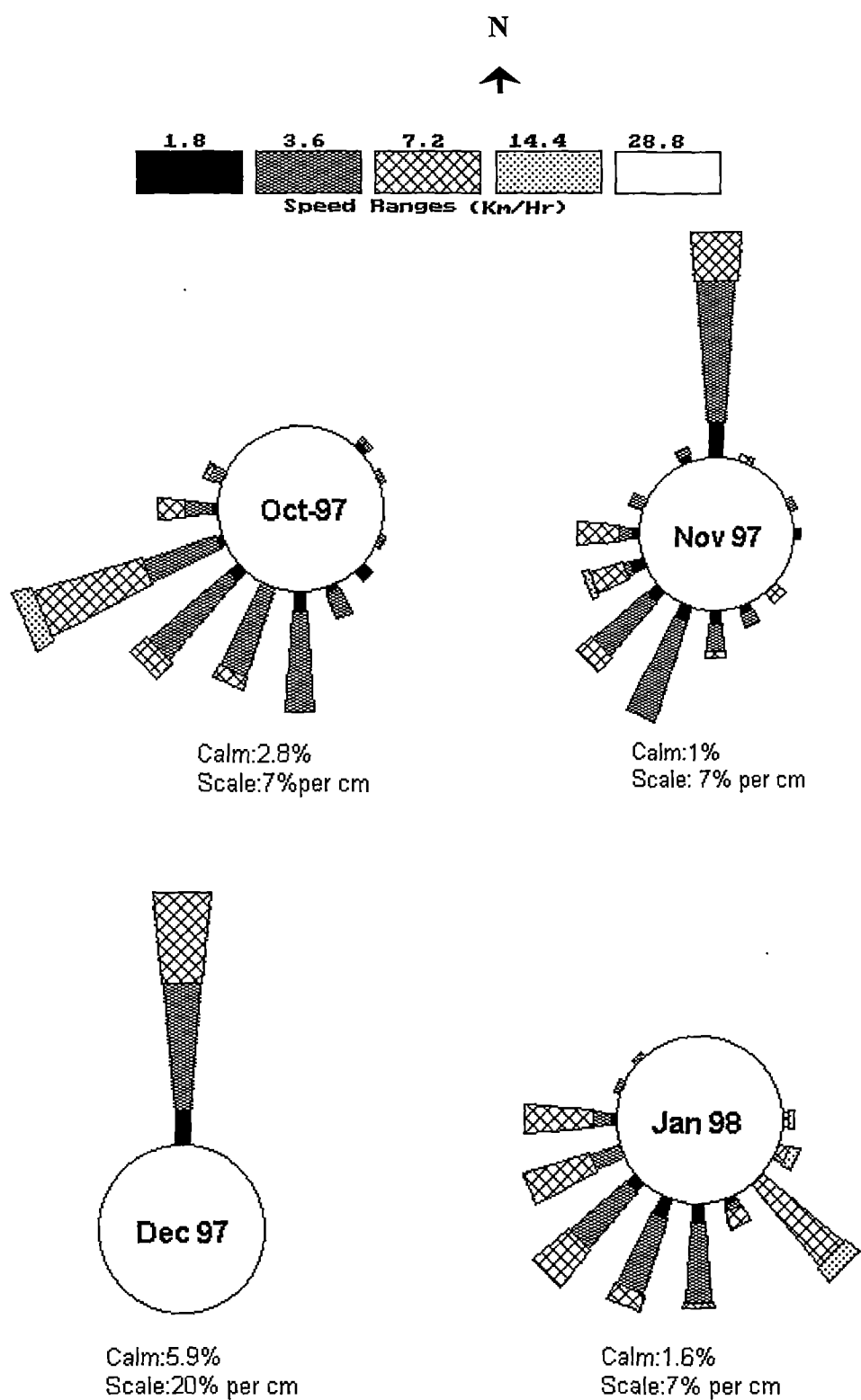


Fig. 2.9. Wind rose diagram showing diurnal (9-17 IST) wind characteristics during some sampling months

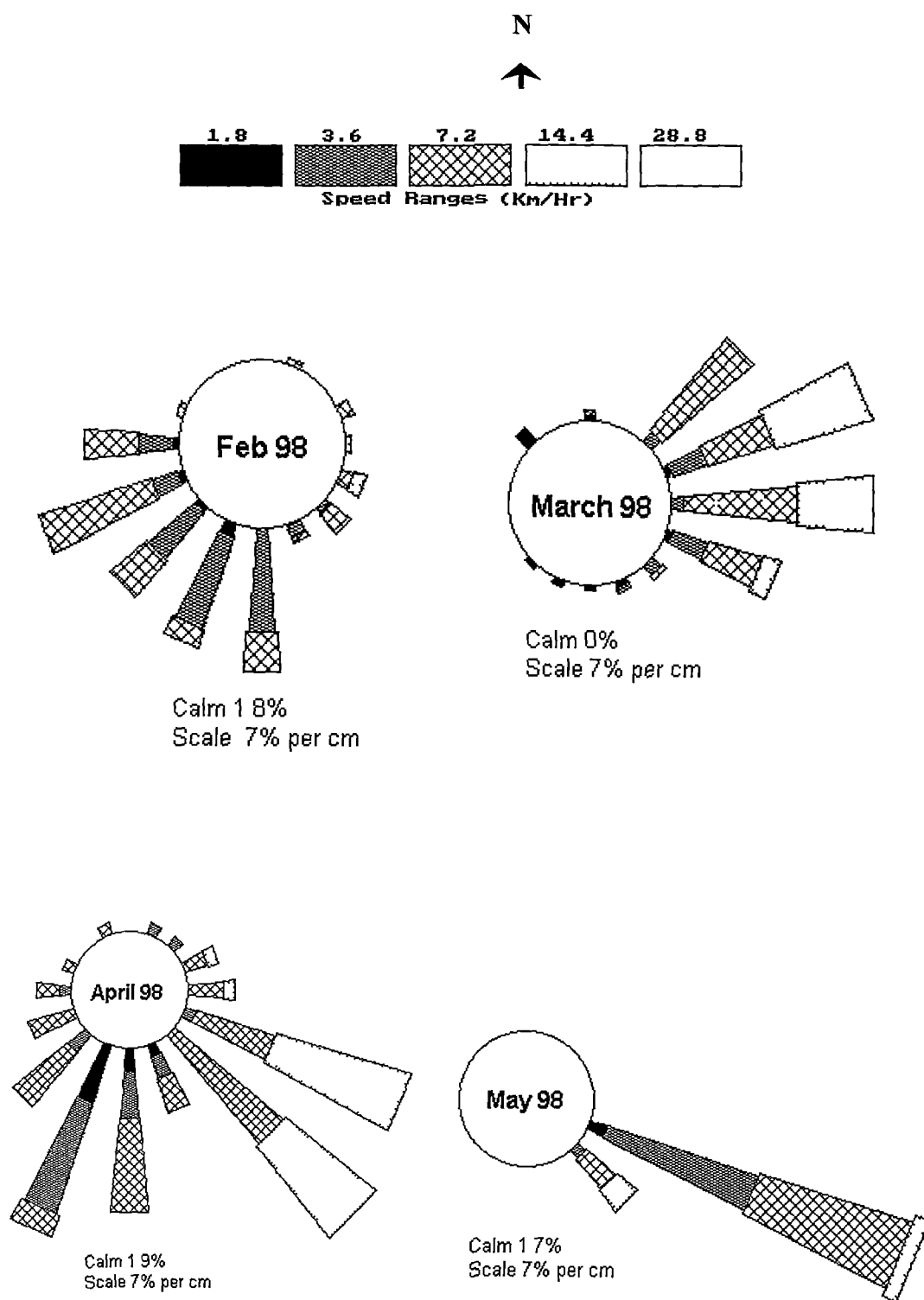


Fig. 2.10. Wind rose diagram showing diurnal (9-17 IST) wind characteristics during some sampling months

wind direction and rainfall. Other important factors are atmospheric stability and mixing heights.

The meteorological conditions in Shillong often change very frequently. The sampling was performed during the dry periods (Oct. to mid May) covering almost eight months duration of a year. During such long periods of a year, significant variations in meteorological characteristics are imminent and quite natural. To observe these variations, hourly ambient temperature ($^{\circ}\text{C}$), relative humidity (%), and wind speed (km/h) were recorded during sampling hours using portable max-min thermometer, hygrometer and anemometer. The hourly average wind direction ($^{\circ}$ from north) and rainfall (mm) were taken from the fixed weather monitoring station located at one of the control site situated at Lumpyngngad using an Envirotech WM 200 system.

Obtained data indicated that the rainfall was quite low and sky conditions were partially cloudy to fully overcast during the sampling periods. As such, the details regarding rainfall and sky conditions are not included in the tabular form here. The mean ambient temperature, relative humidity, wind speed and wind direction recorded during sampling hours of 9-17 IST are provided in Appendix-II (Tables A.2.1 to A.2.16).

2.4.1 Ambient temperature

The air molecules are in constant motion. The speed of air molecules corresponds to their kinetic energy, which in turn corresponds to the heat energy in the air. The ambient temperature is the measure of the average speed at which air

molecules are moving. The mean ambient temperature recorded during sampling hours of 9-17 IST is provided in Tables A.2.1 to A.2.16. If we consider the temperature variations during the sampling periods of 1997-98 and 1998-99 that covers seasons of autumn, winter and mild summer, we see that it varied from a minimum of 11.2 °C to a maximum of 26.7 °C with a peak value of 30.1 °C.

2.4.2 Relative humidity

Relative humidity (RH) is the ratio of amount of water vapor in the air compared to the maximum amount of water that the air can hold at a particular temperature. Generally, the RH values are high in Shillong excluding some extreme winter months. The mean RH values recorded during sampling hours of 9-17 IST are provided in Tables A.2.1 to A.2.16. The RH at all the locations during sampling varied from a minimum of 33.5% to a maximum of 87.5% with a peak value of 99%.

2.4.3 Wind speed

Wind is air in motion. It is caused by horizontal variations in the air pressure. If the difference in air pressure between any two places at the same altitude is more, the wind speed (WS) will be fast. Wind speed is the rate at which the air moves past a stationary object (ELZ, 2000). The wind at any point is the composite of many motions of different sizes. These motions include planetary, synoptic, meso scale and micro scale motions. The WS at the sampling locations during sampling hours of 9-17 IST varied from a minimum of 3.1 km/h to a

maximum of 23.8 km/h with a peak value of 29.1 km/h (Tables A.2.1 to A.2.16).

2.4.4 Wind direction

Wind direction (WD) is the measurement of direction from which the wind blows. It is measured either in points of compass or in Azimuth degrees, which is the angular distance from zenith to the horizon angle measured clockwise from the north. The WD at the sampling locations during sampling hours of 9-17 IST varied from 56.0 ° to a maximum of 358.1 ° with a maximum value of 359.8 °. Thus, we observed that the wind direction during sampling changed from ENE to almost N direction and the changes in WD were quite frequent (Tables A.2.1 to A.2.16).

CHAPTER 3

CHAPTER 3

DETERMINATION OF MASS LOADINGS OF SUSPENDED PARTICULATES, SOOT AND OIL-DROPS AT BREATHING LEVEL

3.1 INTRODUCTION

TSP or aerosols are currently eliciting strong research interests because of their importance in influencing climate, restricting visibility and causing adverse effects on human health. The latter effect caused great concern and led to the identification of TSP as an important pollutant criterion under the Indian NAAQS. The standards set for TSP applies to the mass, which consists of the particles that may remain suspended in the atmosphere, but that may or may not be inhalable into the human body (Chow, 1995). The elevated TSP levels are now a global concern but the problem is more acute in a developing country like India, which could hardly control its air polluting activities despite its anti-pollution policies and measures. This has resulted in considerably higher TSP concentrations in the urban atmospheres. The tropical climatic conditions in most parts of the country are another important factor that adds up to the already elevated TSP levels.

Airborne soot or elemental carbon is the largest contributor to the total particulate burden in the urban atmosphere (Puxbaum *et al.*, 1984). Soot particles display properties of interests in addition to their mass concentrations. These properties attract attention from the point of view of their control. Soot particles, by virtue of their size, contribute to light scattering and absorption and hence both to visibility reduction (Groblicki. *et al.*, 1981; Larson *et al.*, 1988; Larson *et al.*, 1989) and to the earth's radiation balance (Cess, 1983; Porph *et al.*, 1982; Rosen *et al.*, 1981). Fine soot particles, which are hydrophobous adhere more strongly to the deposition surface and are less easily resuspended or washed out by wind or rain and, as such, are the main cause of soiling of external surfaces in the urban atmosphere (Mansfield *et al.*, 1991). The problem is supposed to be more pronounced in third world countries where the levels of soot are very high (De Koning *et al.*, 1986; Jourmand, 1993; Smith, *et al.*, 1996; Yousufzai, 1991). Soot particles are also dominant light absorbing species in the atmosphere and thus are of particular importance. Air quality standards for soot has been recently established in Germany and diesel exhaust aerosol is presently being reviewed to determine if it should be declared to be a toxic air contaminant in USA (Gray *et al.*, 1998). Soot is emitted from more than 70 different types of air pollution sources. Obvious among these include petrol powered motor vehicles, diesel vehicles, and other fossil fuel burning activities including wood smoke and food cooking operations. In addition, there are fugitive sources including the carbon contents of the paved roads, tire dust and vehicular break lining wear particles. Though soot concentrations and its properties were extensively studied in the U.S.

and some European countries (Fassi-Fihri *et al.*, 1997; Herring *et al.*, 1997), the data for the same on the urban atmosphere of our country are hardly available thus necessitating the need for its assessment in the Indian conditions.

Aerosols contain solid and liquid particulates of varying sizes, shapes and chemical compositions suspended in the atmosphere. The liquid particulates or oil-drops (OD) in atmosphere have both anthropogenic and biogenic origins. Uncombusted or partially combusted petroleum residues of high molecular weight hydrocarbons are a major anthropogenic source of OD. The most abundant natural source of OD is coniferous forests, which emit terpenes while deciduous forests release isoprenes. Isoprenes emission depends on solar radiations and air temperatures; therefore, isoprenes are emitted during daytime only (Fontan *et al.*, 1985). The emission of terpenes is dependent mainly on temperature. Between 17°C to 32°C, the emission is multiplied by a factor of 5 (Tinghey, 1981). Volatilization of terpenes is controlled by diffusion rates and vapor pressure of the constituents. A large release of terpenes occurs at the end of the growing season or after a stress on the vegetation. The concentration of OD or hydrocarbons is of special interest because of their highly reactive nature in the atmosphere. The isoprenes are almost 50 times as reactive to OH radical as the anthropogenic hydrocarbon blends (Fontan *et al.*, 1985). The aspect of determination of OD concentrations in high vehicular activities areas of urban atmospheres in India is of particular interest because of the high number of two stroke vehicles and poorly maintained engine conditions. It gains further significance in areas having high vehicular as well as vegetation density of coniferous forests.

In the present work, we have briefly discussed different sampling methods for TSP in section 3.2. Aspects on the experimental set up have been described in section 3.3. Section 3.4 deals with the results and discussion parts that include TSP concentrations, cluster analysis to draw hierarchical plots to group sampling locations on the basis of TSP for various categories, categorization of sampling locations into low ($<0.5S$), moderate (between $0.5S$ to $1.0S$), high (between $1.0S$ to $1.5S$) and critical ($>1.5S$), where S is the 24 hours standard for TSP ($100 \mu\text{gm}^{-3}$) as notified under Indian NAAQS for sensitive areas (Shillong falls under sensitive area due to its status as a major hill station), correlation of TSP with traffic density and meteorological variables, soot concentrations, interrelationship of soot with TSP, correlations of soot with traffic density, OD concentrations and its correlations with traffic density and meteorological variables. The conclusions of this part of study are drawn in the section 3.5.

3.2 SAMPLING METHODS FOR TOTAL SUSPENDED PARTICULATES

Initially, the people detected air pollution with their lungs, noses and eyes. The more obvious indicator would have been a visible cloud resulting from scattering and absorption of light by suspended particles. Over the years, various methods have been evolved for collection of TSP in ambient air. The most widely used methods include dust fall method (ASTM, 1970; Chapman, 1955; Egami *et al.*, 1989; Herrick, 1966), British Smoke Shade measurement, U.S. Coefficient of Haze method (ASTM, 1985; Hemeon *et al.*, 1953; Herrick *et al.*, 1989) and high-volume sampling method. The measurement methods evolved by Indian Standard Institution

for TSP (IS: 5182 (IV), 1973) and Indian NAAQS, 1982 (modified in 1994) also recommend high-volume sampler as the sampling device.

It has been observed that the opening underneath the high-volume sampler's peaked roof inlet allow dust to blow onto the filter before and after sampling resulting in significant passive depositions (Blanchard *et al.*, 1978; Bruckman *et al.*, 1976; Chahal *et. al.*, 1976; Swinford, 1980). The glass fiber filters commonly used in high-volume samplers have also been found to absorb abundant quantities of sulfur dioxide and oxides of nitrogen adding several μgm^{-3} to the samples. It has also been noted that the high-volume blower exhaust contained carbon and copper particles from the motor brushes and armature and that a portion of these particles are recirculated to the filter (Countess, 1974).

To minimize the inherent problems of high-volume sampling methods and to determine particle size distributions and elemental concentrations, we have used a different sampling device in place of high-volume samplers for collection of TSP. The method used is as recommended by Indian Standards Institution (ISI) for collection of particulates by filtration and determination of mass loadings, number and optical sizing of the atmospheric particulates (IS: 5182(XVI), 1980). The experimental setup for collection of TSP is described in the subsequent section of 3.3.

3.3 EXPERIMENTAL SETUP

3.3.1 Sampling equipment

To collect TSP, the equipment should be able to draw a measured and

representative sample of the atmosphere through a filter medium. The membrane filter or low volume air sampler fulfills these requirements and as such the same were used for collection of TSP. The equipment was fabricated by M/S Envirotech Instruments, Delhi as per the design drawn by us on the basis of the ISI method (IS: 5182(XVI), 1980). The schematic diagram of the low volume air sampler is shown in Fig. 3.1. The basic feature of the equipment includes a suction pump to draw air through the filter medium, a filter holder assembly, a flow meter to calculate the volume of air drawn, a time totalizing device and filter medium.

(a) Suction pump

The suction pump used has a brush less pump (1/6 HP motor) with high vacuum efficiency and the required flow volume. The pump was lightweight making it handy and portable.

(b) Filter holder assembly

The filter holder assembly used for sampling is shown in Fig. 3.2. The assembly consists of a filter holder base and a top cover fabricated with aluminum metal. The filter holder base had a S.S. mesh, 'O' ring and limiting orifice and the top cover with 'O' ring. Three screw ports were provided to tighten the filter holder base and top cover together. The holder was designed in a manner to hold 47 mm dia membrane filter without wasting any filtering area. An inert metal screen made up with stain less steel was provided to prevent rupture or displacement of the filter. The top view of the filter holder base shows a clear view of S.S. Screen, 'O' ring

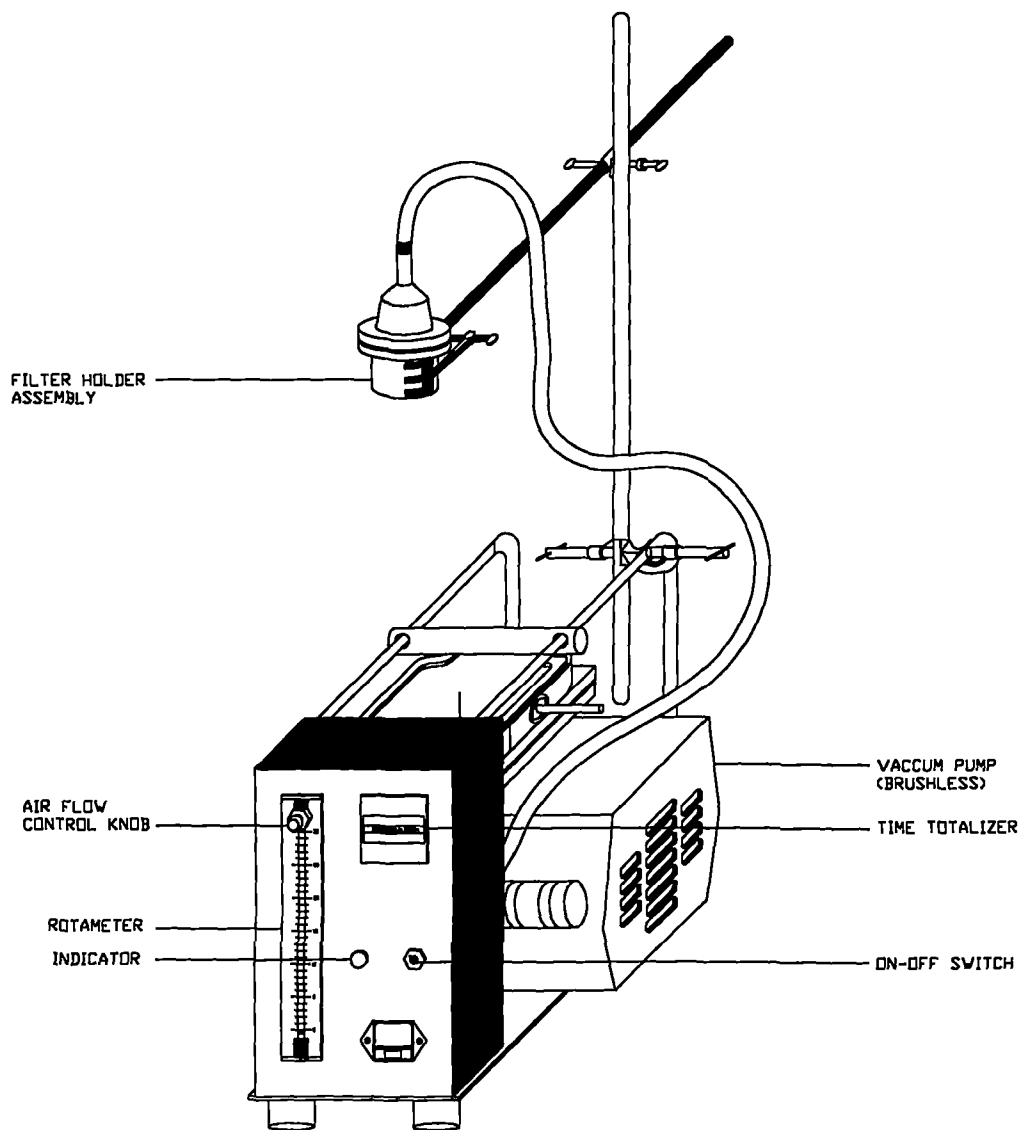


Fig.3.1. A schematic view of low volume air sampler

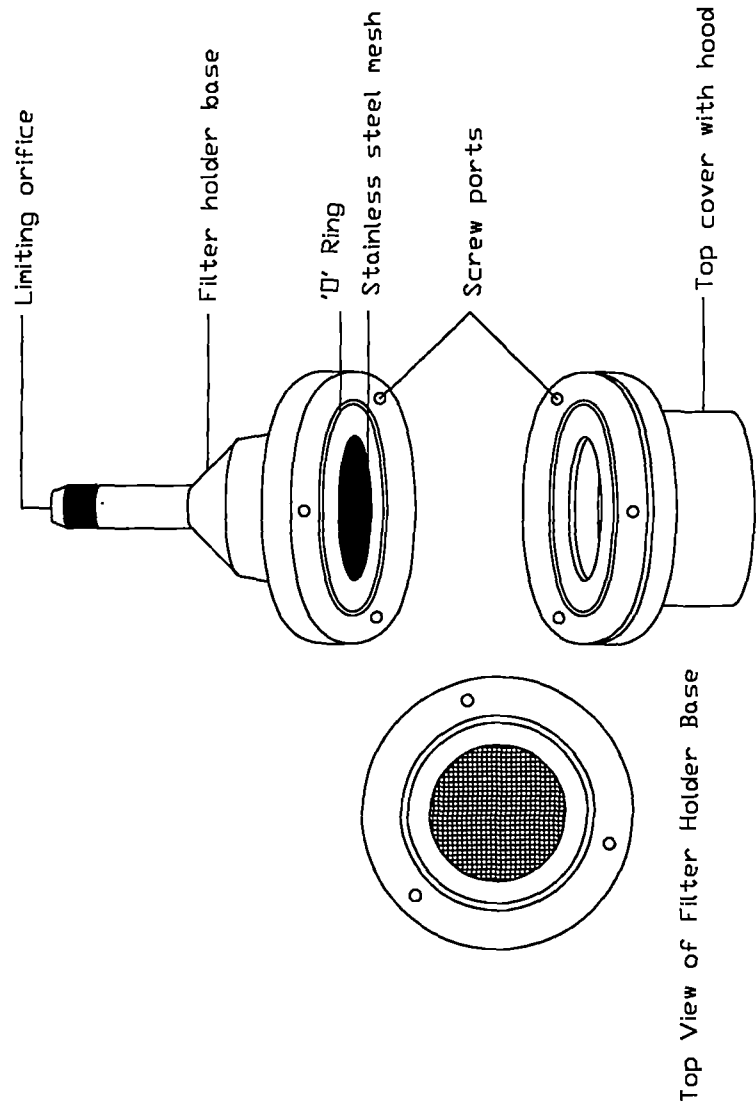


Fig.3.2. A schematic view of filter holder assembly

and screw ports (Fig. 3.2) The 'O' ring was provided to avoid the chances of channeling or leak around the filter. The function of limiting orifice was to restrict the rate of airflow coming into the device. The holder was designed to have uniform flow through the filter medium.

(c) Flow meter

The device used for flow measurement was a precalibrated "Rotameter". It consisted of a plummet or float, which was free to move up and down in a vertical slightly tapered tube. The air entered through the lower end of the tube. The float obstructed the airflow and a pressure difference arose between the front and rear of the float. The float was lifted up by the resultant upward force, and reached a point where the pressure was balanced by its effective weight. The distance of the float movement was corrected to the flow volume.

(d) Filter medium

A particle sampling filter consists of a tightly woven fibrous mat penetrated with microscopic pores. Several characteristics are important in selecting a filter media. The particle sampling efficiency of filters should be to remove 99% of suspended particles drawn through them regardless of particle size or flow rate. The mechanical stability of filters should be such that it should lie flat in the sampler, remain in one piece, and provide a good seal with the sampling system to avoid leaks. The filter must have strong chemical stability and it should not react with the deposit, even when submitted to strong extraction solvents. The temperature stability

should be to retain their porosity and structure in the presence of temperatures typical of the sampled air stream and analysis methods. The blank concentrations of filters should not contain significant and highly variable concentration of chemicals, which are being sought by analysis. The flow resistance and loading capacity of filters should allow sufficient amount of air to be drawn through them to satisfy the flow requirements of inlet and obtain an adequate deposit. The collected particles should not clog them to the extent that flow rates decrease between them.

Nitro-cellulose membrane filters have been used in the present study. They are best suited for low volume air samplers as they satisfy most of the requirements. These membrane filters have high flow resistance, negligible ash content, dissolves in many organic solvents, less hygroscopic, low blank weights and are suitable for gravimetric, optical microscopy and scanning electron microscopic analysis.

(e) Time totalizing device

A time totalizing device was also incorporated in the sampling equipment with least measurement facility of 0.6 minutes. The device was incorporated to calculate any power failures during the sampling period.

3.3.2 Collection of total suspended particulates samples

Prior to placement of low air volume sampler at a particular site, it was established that the sampler be placed to yield data representative of the location and should not unduly be influenced by the immediate surroundings. The fulfilment of objectives of the study was taken into consideration and constraints to air flow from

any direction was avoided.

Accordingly, low volume air samplers were placed along the roadsides on pavements (1.0 meter distance from road and 1.5 meter above ground level) during peak activity hours (9-17 IST). The sampling period was from November 1997 to May 1998 and October 1998 to May 1999 (dry seasons). Two number of air samplers were used simultaneously at two different locations for sampling. Prior to initiation of monitoring programme, both the samplers were operated at a control location to evaluate difference in TSP collection efficiencies. These have been found to be almost insignificant (within 5%).

3.3.3 Conditioning of filter papers

Nitro-cellulose filters (Millipore) of 47 mm dia with pore size of 0.30 μm were used for TSP sampling. Prior to and after the collection of TSP, the filter papers were conditioned at 30°C for 24 hours. After conditioning, filter papers were kept in airtight containers inside the vacuum desiccator and were allowed to cool down to room temperatures for weighing. The filters papers were weighed with the help of a microbalance with the precision of $\pm 10 \mu\text{g}$. During transit from laboratory to field, the filter papers were carried in airtight containers to avoid any chances of contamination.

3.3.4 Collection and estimation of total suspended particulates

In clean filter holder, a pre weighed filter paper was meticulously fixed. The air sampler's flow-rates were adjusted at 15 liters per minute with the help of the

precalibrated rotameter. The filter holder was kept facing the ground to avoid collection of bigger non-inhalable suspended particulates, which might settle due to gravity. The sampling arrangement is shown in Fig. 3.3. Normally, 7.2 M^3 of air was drawn through the filter, which provided enough mass loadings for carrying out requisite analysis works (APHA, 1977).

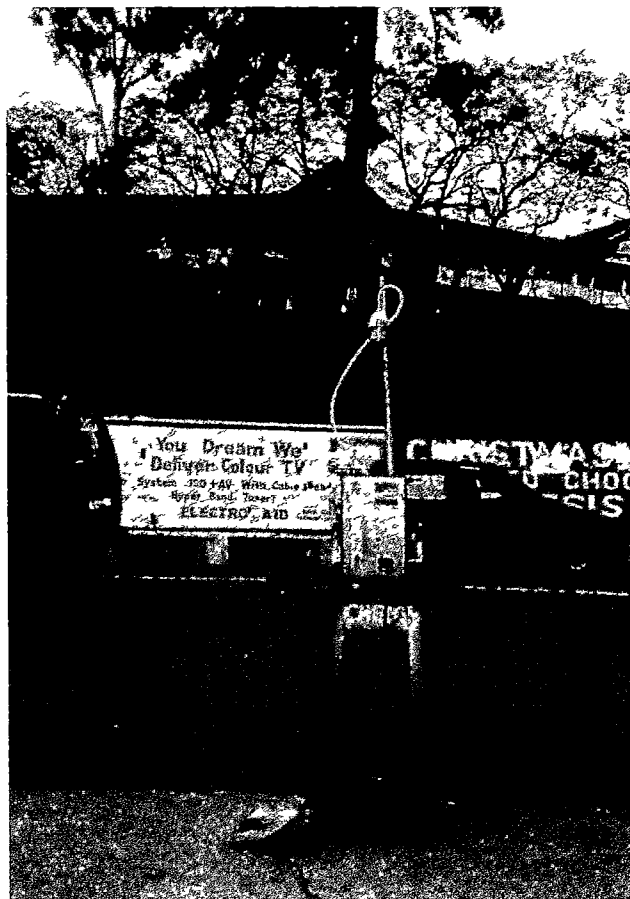


Fig. 3.3 A view of sampling arrangement

The sampling protocols were also evolved for noting the accurate site characteristics, meteorological variables, vehicular density, rotameter flow rates, sample color etc. during sampling. The details of these protocols are given in

Appendix–III (Tables A.3.1 and A.3.2). The concentration of TSP had been calculated gravimetrically from the difference in the initial and final weights of the filter papers and suction flow rates using the method as per the “Methods for Air Sampling and Analysis” (APHA, 1977).

3.3.5 Estimation of soot

A small amount of particulate matter was carefully removed from the filter papers. A known weight of the sample was dissolved in 10 ml of conc. HNO_3 and the solution was then heated to dryness. The contents were dissolved again in 10 ml of 20% HNO_3 . The prepared solution was then quantitatively filtered through a micro-filtration unit using pre-weighed nitro-cellulose filters of diameter 25 mm (preconditioned at 30°C for 24 h) having pore size of $0.80\ \mu\text{m}$. All chemicals used were of analytical grade (AR Grade). The filter papers containing soot as residue were dried at 30°C for 24 h and then weighed on a microbalance. The soot contents were calculated similarly as the TSP concentrations (APHA, 1977). Some filter papers containing soot as residue were placed in pre-weighed silica crucibles and ignited in a muffle furnace at 550°C for one hour. After ignition, the silica crucibles were kept in a desiccator for a sufficient period of time to cool down to room temperature. The absence of any residue in the ignited silica crucible confirmed the contents as soot. The analysis of soot in TSP was performed only for the 1st sampling conducted during Nov 1997 to May 1998.

3.3.6 Determination of oil-drop concentrations

The concentration of OD in aerosols was determined using an optical microscope (Laborlux D, Leitz, Wetzlar, Germany) at a magnification of 1562X and are discussed as relative abundance (in %) in comparison with the solid particles. The aspects of slide preparations and measurement methodologies are discussed in detail in Chapter 4, which deals with particle size determination of suspended particulate matter.

3.4 RESULTS AND DISCUSSION

3.4.1 TSP sample colors

The observance of TSP sample color is a qualitative approach that provides a fair indication about the possible source of particulate loadings at a given location. The sampling dates and sample color have been provided in Appendix-III (Tables A.3.3 to A.3.14). The obtained sample colors had been categorized into three categories of gray, dark gray and black. The gray color of the sample indicated TSP loadings of mostly natural occurrence. The dark gray color indicated some impact of soot generating anthropogenic activities. The black color of samples clearly indicated the presence of soot from vehicular exhaust emissions and other fuel combustion activities. The colors of few samples collected at CB, MP, MU, HP, HU, Fire Brigade Traffic Intersections (TIF) and various elevations specific locations (A locations) are shown in Fig. 3.4 to 3.6 respectively.

The color of TSP loadings at CB locations was found to be gray (Table

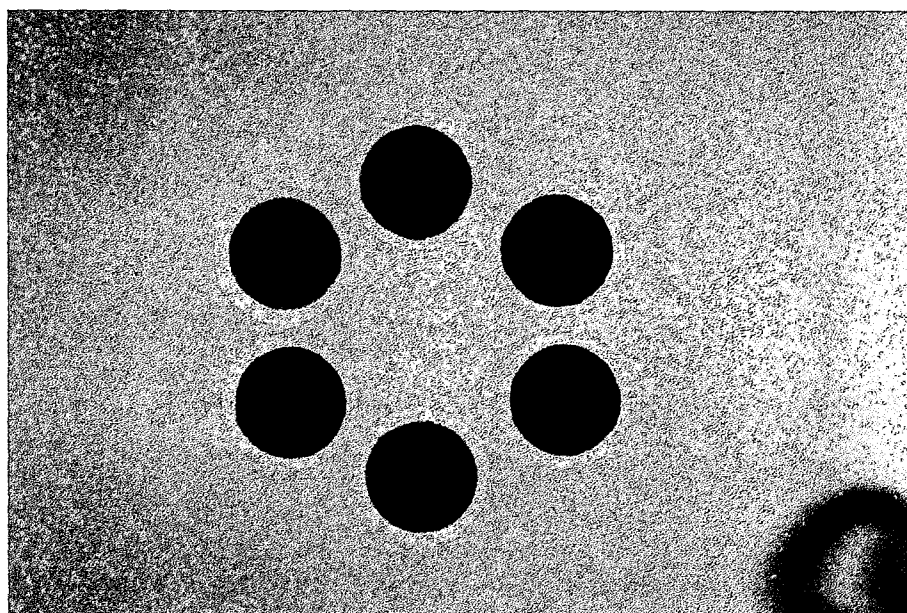


**Fig. 3.4 Membrane filters showing sample colors
at some CB, MP, MU, HP and HU locations**

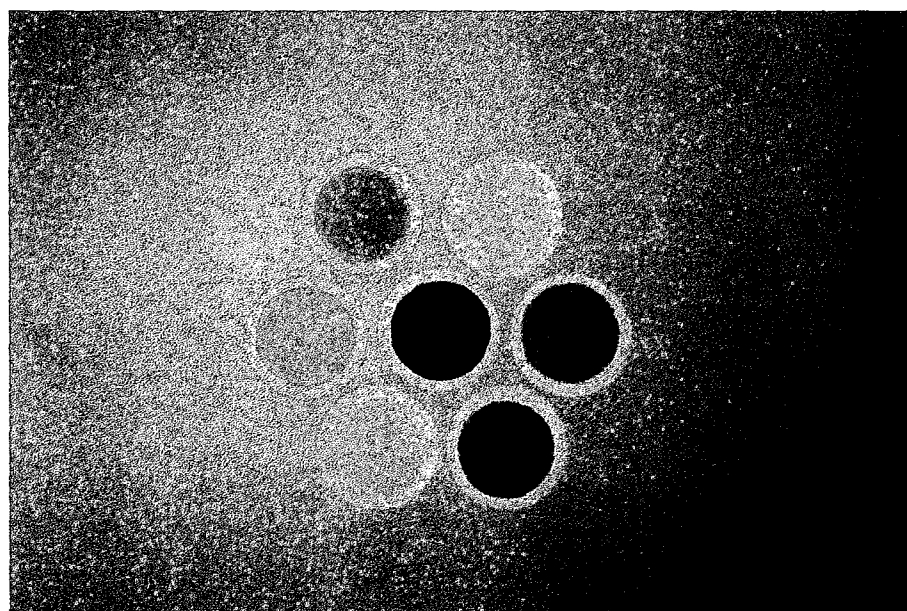


**Fig. 3.5 Membrane filters showing sample colors
at TIF locations**

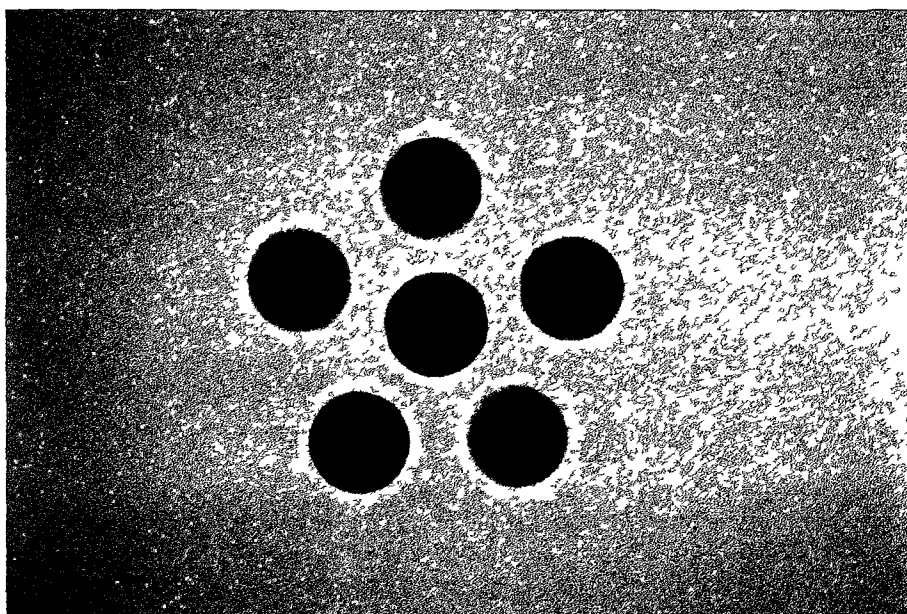


Fig. 3.6 Membrane filters showing sample colors at elevation specific (A) locations

A.3.3). Since the anthropogenic activities at CB locations were low, the mass loading at these locations provided color of background TSP concentrations at breathing level of Shillong and as such was of natural occurrence. The sample colors at MP locations had been gray, dark gray and black in color (Table A.3.4) implying impacts of anthropogenic activities with varying intensity, while at MU locations (Table A 3.5) they were mostly black and sometimes dark gray. The mostly black color at MU locations indicated increase in soot levels mostly by motor vehicles, as these locations were positioned either on highways or on major city roads. Almost similar observations, as noted in the case of MP and MU locations, were also made for HP and HU locations (Tables A.3.6 and A.3.7). At traffic intersections, the sample colors of the locations on highways were generally black but on across

direction locations they were mostly gray ((Tables A.3.8 to A.3.10). The sample colors of H locations were black while they were gray at IN locations (Tables A.3.11 and A.3.12). The IE1 showed gray sample color while IE2 showed black color. It is understandable as the IE1 location was surrounded by pine forests and had no air polluting industries/activities while IE2 was located on highway with impacts of industrial/vehicular emissions and other polluting activities (Table A.3.13). The sample colors at A locations changed from black to dark gray even at a difference of only about 6 meters but continued to be same up to 17 meters of height (Table A.3.14).

Clark, E. (1995) had found deposition of deep brown and black colors for aerosol samples on filter papers and he also attributed black depositions as indication of traffic exhaust emissions.

3.4.2 TSP concentrations

For clear view in TSP data presentation, we have divided our discussions into four sub-sections. In sub-section 3.4.2, we have compared the cumulative mean TSP values at various categories of sampling locations with that of the other major cities in India and the world. The temporal variations in TSP at all categories of sampling locations are discussed in sub-section 3.4.3. This sub-section also includes hierarchical plots (tree cluster algorithm to join sampling locations into successively larger clusters using some measure of similarity or distance) drawn by single linkage method that puts closets objects together, discussions on Euclidean distances of hierarchical plots (geometric distance in the multidimensional space computed as,

distance $(x,y)=\{\sum_i (x_i-y_i)^2\}^{1/2}$) and categorization of sampling locations as “low”, “moderate”, “high” and “critical” according to Indian NAAQS. The linear relationship of TSP with traffic density at MP, MU, HP and HU locations constitutes sub-section 3.4.4. This sub-section also includes the Pearson correlation coefficients of TSP with traffic density. The sub-section 3.4.5 deals with the Pearson correlation coefficients of TSP with meteorological variables. All statistical analysis had been performed with the help of the software “STATISTICA” Release 4.5 of StatSoft, Inc., 1993.

The cumulative mean TSP concentrations for various categories of sampling locations in Shillong are given in Table 3.1. The TSP at CB locations was found to be about $50 \mu\text{gm}^{-3}$. These locations had somewhat similar characteristics with respect to climate and traffic as at Ridge, Shimla (India) and Payerne, Switzerland where the TSP were $161.1 \mu\text{gm}^{-3}$ and $30.0 \mu\text{gm}^{-3}$ respectively. (Tables 3.2 and 3.4). The TSP at CB locations had been low in comparison with Ridge, Shimla but moderately higher with regard to the Payerne, Switzerland. At MP locations, the mean TSP concentrations increased to 5.5 times that of the CB values with peak value of $478.2 \mu\text{gm}^{-3}$. At MU locations, the TSP values were 1.3 times higher than the MP locations and 7.2 times higher than CB locations with the peak value of $496.4 \mu\text{gm}^{-3}$. HP locations had mean TSP value of $311.5 \mu\text{gm}^{-3}$ with peak value of $491.7 \mu\text{gm}^{-3}$, which was 6.2 times higher than the values at CB locations. The HU locations had mean value of $412.3 \mu\text{gm}^{-3}$ and the peak value of $664.3 \mu\text{gm}^{-3}$, which showed 8.2 times increase in TSP to that at CB locations. The MU and HU locations

Table 3.1 TSP concentrations at various categories of locations in Shillong (μgm^{-3})- this study					
S No	Location	Mean	Max	$\pm$SD	Sample Size
1	CB	50.5	56.2	4.89	6
2	MP	275.9	478.2	104.40	31
3	MU	363.7	496.4	102.50	27
4	HP	311.5	491.7	113.90	35
5	HU	412.3	664.3	139.50	26
6	TIF0	449.1	467.6	26.19	2
7	TIB0	198.6	208.3	13.76	2
8	TIG0	581.7	774.6	272.70	2
9	H	300.4	383.2	117.15	4
10	IN	90.3	96.1	8.15	4
11	IE	530.7	825.3	416.58	4
12	A0	355.3	430.6	106.50	2

recorded higher TSP values in comparison with the plain locations of MP and HP.

The TSP results at MP, MU, HP and HU locations in Shillong were found to be moderately higher with the mean TSP concentrations of $341 \mu\text{gm}^{-3}$, $275 \mu\text{gm}^{-3}$, $359 \mu\text{gm}^{-3}$ and $404 \mu\text{gm}^{-3}$ recorded for the Indian cities of Delhi, Kolkata, Patna and Kanpur respectively by CPCB under NAMP (Table 3.3). The higher TSP values in Shillong are attributable to the fact that the monitoring criteria adopted in studies undertaken for different parts of country were generally different than ours, which included placement of samplers at varying heights, different climatic conditions, dissimilar equipments and methodologies used etc. The higher TSP concentrations at locations situated on highways/major roads were an explicit indication of the direct impact of vehicular emissions on breathing level air quality in Shillong. The TSP concentrations at city centres of European countries of Oporto Portugal were $35 \mu\text{gm}^{-3}$ while in Geneva, Switzerland it was $42 \mu\text{gm}^{-3}$. In other major cities of the world, it ranged between $35.2 \mu\text{gm}^{-3}$ in Kashima, Japan to $119.7 \mu\text{gm}^{-3}$ in Jakarta,

Table 3.2 TSP concentrations in other cities of India (μgm^{-3})					
S No	Location	Mean	Max	Reference	Remarks
1	Paonta Sahib, Himanchal Pradesh	243.9	772.9	Gupta <i>et al.</i> , 1998	Residential area
2	Shyambazar, Kolkata	259.4	706.7	Mandal, 1999	Residential area, rooftop
3	Gariaghat, Kolkata	228.0	599.8	Mandal, 1999	Residential area, rooftop
4	Salt Lake, Kolkata	228.0	599.8	Mandal, 1999	Residential area, rooftop
5	Ridge, Shimla	161.1	324.7	Gupta <i>et al.</i> , 1994	Residential area with no traffic movements
6	Winter Field, Shimla	253.8	322.9	Gupta <i>et al.</i> , 1994	Commercial area
7	Delhi Gate, Udaipur	772.0	840.0	Joshi <i>et al.</i> , 1991	Commercial area
8	Pratap Nagar, Udaipur	208.0	330.0	Joshi <i>et al.</i> , 1991	Industrial area
9	Alambagh, Lucknow	3450.0	-	Pandey <i>et al.</i> , 1998	Commercial area, 10 M height
10	Charbagh, Luknow	3241.0	-	Pandey <i>et al.</i> , 1998	Commercial area, 10 M height
11	Chinhat, Lucknow	1858.0	-	Pandey <i>et al.</i> , 1998	Suburban, 10 M height
12	Hazaratganj, Lucknow	1800.0	-	Pandey <i>et al.</i> , 1998	Traffic intersection, 10 M height
13	Qaiserbagh, Lucknow	1075.0	-	Pandey <i>et al.</i> , 1998	Traffic intersection, 10 M height
14	Therubali, Koraput	82.2	-	Mohanty, 1998	Rural
15	Damanjodi, Koraput	91.2	-	Mohanty, 1998	Commercial
16	Venkittapuram, Coimbtore	2258.0	-	Meenambal <i>et al.</i> , 1999	Commercial
17	Cowley Road, Coimbtore	723.0	-	Meenambal <i>et al.</i> , 1999	Sensitive
18	Chatham, Port Blair	123.4	221.0	Mahajan, 1996	Commercial

Indonesia except in Riyadh, Saudi Arabia where it was $639 \mu\text{gm}^{-3}$ (Table 3.4). In general, the TSP concentrations in Indian urban atmosphere are high in comparison

Table 3.3 TSP concentrations (μgm^{-3}) in major cities of India during 1998 under NAMP (CPCB, 2000)					
S No	Location	Residential		Industrial	
		Mean	Max	Mean	Max
1	Delhi	341.0	-	367.0	-
2	Mumbai	103.0	654.0	226.0	383.0
3	Kolkata	275.0	785.0	286.0	666.0
4	Chennai	116.0	335.0	126.0	453.0
5	Bangalore	239.0	589.0	134.0	346.0
6	Hyderabad	167.0	586.0	259.0	1000.0
7	Patna	359.0	1161.0	-	-
8	Bhopal	287.0	887.0	384.0	508.0
9	Nagpur	149.0	364.0	138.0	333.0
10	Pune	247.0	324.0	374.0	649.0
11	Jaipur	209.0	776.0	248.0	903.0
12	Kanpur	404.0	832.0	441.0	765.0
13	Chandigarh	229.0	626.0	331.0	844.0
14	Pondicherry	201.1	523.0	-	-

with the other cities of the world. The TSP concentrations of $3450 \mu\text{gm}^{-3}$ was recorded at the commercial place of Alambagh, Lucknow during 9-11 IST at an elevation of 10 meters (Table 3.2) by Pandey *et al.* (1998) were the highest found by us in the available literature.

The TSP values at TIF0 and TIG0 were $449.1 \mu\text{gm}^{-3}$ and $581.7 \mu\text{gm}^{-3}$ respectively with peak values of $467.6 \mu\text{gm}^{-3}$ and $774.6 \mu\text{gm}^{-3}$ while it was only $198.6 \mu\text{gm}^{-3}$ at TIB0 with a peak value of $208.3 \mu\text{gm}^{-3}$. The TIB0 location showed relatively lower TSP values. The low values at TIB0 could be attributed to the better dispersion abilities of this location as it had open surroundings. Pandey *et al.* (1998) obtained TSP values of $1800 \mu\text{gm}^{-3}$ and $1075 \mu\text{gm}^{-3}$ at traffic intersections of Hazaratganj and Qaiserbagh in Lucknow at the height of 10 meter (Table 3.2), which were considerably higher than observed in this study. The TSP concentrations

Table 3.4 TSP concentrations in other cities of the world (μgm^{-3})

S No	Location	Mean	Reference	Remarks
1	Manchester, U.K.	36.0	Miller <i>et al.</i> , 1996	In 1993
2	Oporto, Portugal	35.0	Pio <i>et al.</i> , 1998	Oct 92-Sept 93
3	Geneva, Switzerland	42.0	Monn <i>et al.</i> , 1995	City centre, 3 M above ground level
4	Payerne, Switzerland	30.0	Monn <i>et al.</i> , 1995	Outside village, no road, 2.5 above ground level
5	Jakarta, Indonesia	119.7	Zou <i>et al.</i> , 1997	City centre, commercial and residential
6	Kuala Lumpur, Malaysia	52.8	Rashid <i>et al.</i> , 1995	Valley, 15 M above ground level
7	Chicago, Illinois, USA	49.4	Rashid <i>et al.</i> , 1988	Inhalable Particulates
8	Kashima, Japan	35.2	Okamoto <i>et al.</i> , 1991	Inhalable Particulates
9	Sao Palo, Brazil	81.4	Orsini <i>et al.</i> , 1986	Inhalable Particulates
10	Riyadh, Saudi Arabia	639.0	El-Shoboskshy <i>et al.</i> , 1990	Inhalable Particulates

at H locations were $300.4 \mu\text{gm}^{-3}$ with the peak value of $383.2 \mu\text{gm}^{-3}$ while at IN locations it was $90.3 \mu\text{gm}^{-3}$ with a peak value of $96.1 \mu\text{gm}^{-3}$ thus showing a ratio of 3.3 for outdoor/indoor environments. Our findings differed with that of Baek *et al.* (1997) who observed a ratio of 1.3 in Korea while Monn *et al.* (1993) obtained a ratio of 1.1 for Zürich. The high outdoor/indoor TSP ratios recorded in this study pointed to higher TSP concentrations in the outdoor environment compared to indoors in Shillong. In Indian conditions, Mohan *et al.* (1992) recorded high concentration of TSP in indoor environment ranging from a minimum of $417 \mu\text{gm}^{-3}$ to as high as $1750 \mu\text{gm}^{-3}$ in Pune but the corresponding outdoor TSP concentrations were not observed by them. The TSP concentration at IE locations had been 530.7

μgm^{-3} with a peak value of $825.3 \mu\text{gm}^{-3}$. The industrial areas monitored under NAMP showed TSP concentrations ranging from $126 \mu\text{gm}^{-3}$ at Chennai to $441 \mu\text{gm}^{-3}$ at Kanpur, with a peak value of $1000 \mu\text{gm}^{-3}$ at Hyderabad (Table 3.3). Joshi *et al.* (1991) had recorded $208 \mu\text{gm}^{-3}$ of TSP at the industrial area of Udaipur (Table 3.2). TSP concentrations at IE locations in this study were comparatively higher as one of the industrial locations had vehicular exhaust emissions as an additional major source of TSP due to its location on highway and the steep gradient conditions. The TSP concentration at A0 location was $355.3 \mu\text{gm}^{-3}$ with the peak value of $430.6 \mu\text{gm}^{-3}$.

3.4.3 Temporal variations in TSP concentrations

The temporal variations in TSP provide information about the deviations observed in TSP concentrations at various categories of locations in data sets during samplings in 1997-98 and 1998-99.

The temporal variations in mean TSP concentrations at CB locations (Fig. 3.7) had shown slight variations as it ranged from $47.2 \mu\text{gm}^{-3}$ at CB2 (valley with no vehicular activities) to $56.2 \mu\text{gm}^{-3}$ at CB1 (hilltop with no vehicular activities).

The peak value of $56.7 \mu\text{gm}^{-3}$ was also noted at CB1. The ambient air quality at CB2 and CB3 locations was “low” at 0.5S and “moderate” at CB1 (0.6S) as per Indian NAQSS. The closeness of CB2 and CB3 was further explained with the help of hierarchical plots (Fig. 3.8) that showed small Euclidean distance of 1.9.

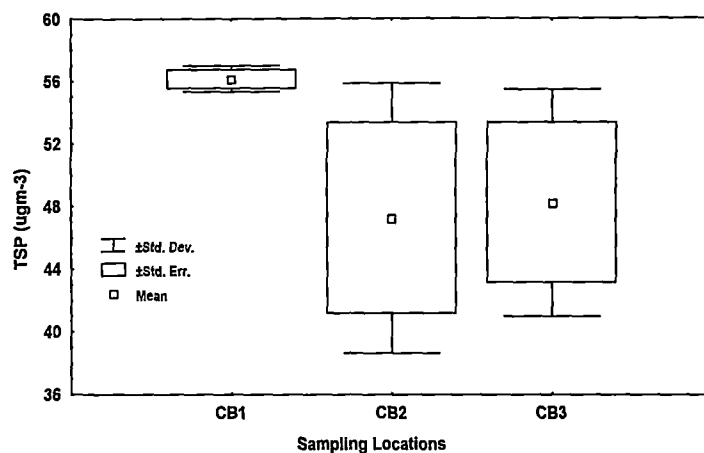


Fig. 3.7 Temporal variations in TSP at CB locations

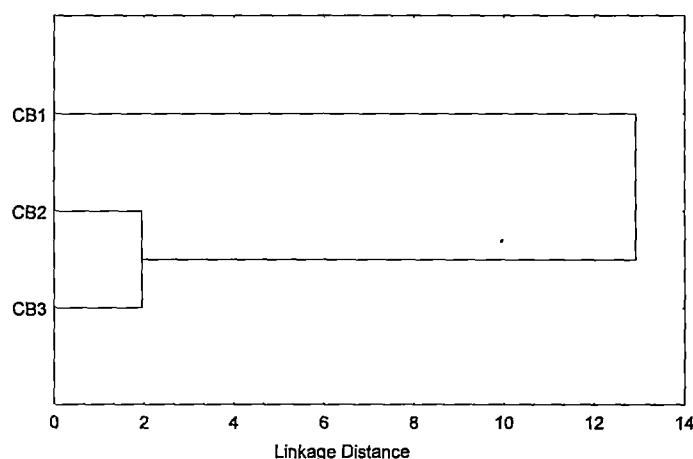


Fig. 3.8 Hierarchical plot of TSP for CB locations

The temporal variations in TSP at MP locations (Fig. 3.9) indicated that the TSP levels gradually increased from the city's entrance point location of MP1, where the mean concentration was $106.4 \mu\text{g}/\text{m}^3$, up to the MP8 location (the busiest commercial area with a local bus stand) where it was $478.2 \mu\text{g}/\text{m}^3$. The TSP showed a drop up to MP11, where it was $180.8 \mu\text{g}/\text{m}^3$ and then it shot up again at MP12 to $262.5 \mu\text{g}/\text{m}^3$. TSP concentrations came down to $292.0 \mu\text{g}/\text{m}^3$ at MP13 location (the exit point of the city). The peak value of $657.1 \mu\text{g}/\text{m}^3$ for TSP was observed at MP8

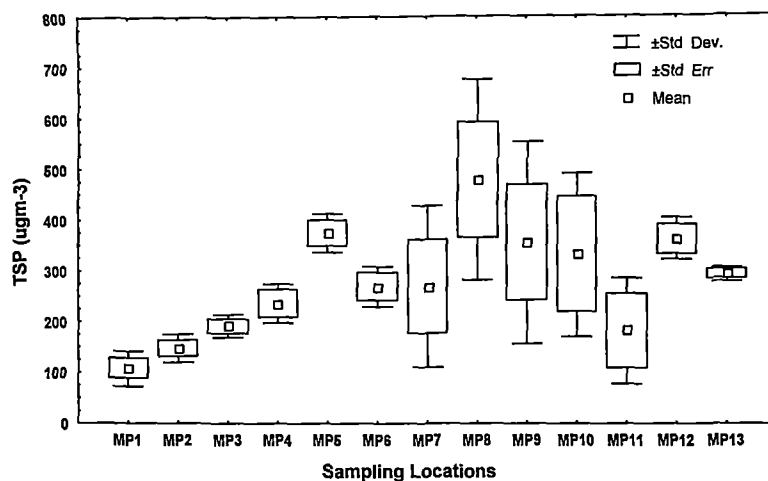


Fig. 3.9 Temporal variations in TSP at MP locations

location. On the basis of Indian NAAQS for TSP, the ambient air quality at MP locations was categorized into “high” at MP1 and MP2 locations (1.1S and 1.5S respectively) and “critical” at rest of the locations (MP3 to MP13) as TSP/NAAQS ratio at these locations ranged between 1.8S to 4.8S. The clustering of MP locations is shown by hierarchical plot (Fig. 3.10). It was observed that except the MP8

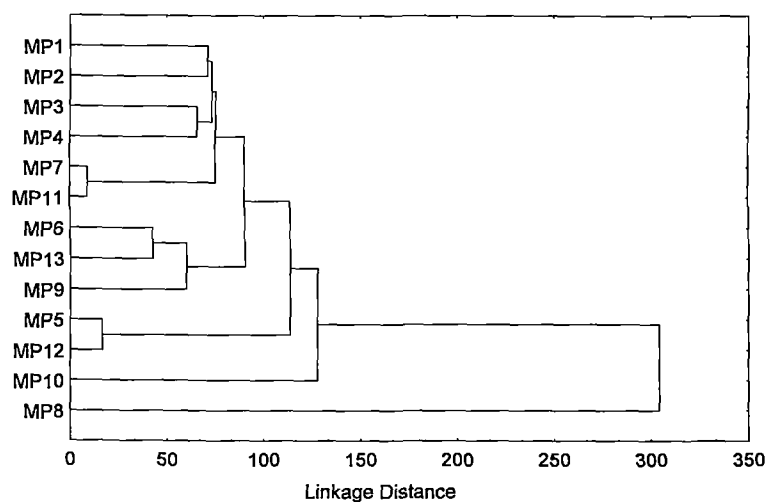


Fig. 3.10 Hierarchical plot of TSP for MP locations

location, which was the high commercial activity area with a bus stand, restaurants etc., the rest of the MP locations could be grouped within a Euclidean distance of about 130 thus showing certain closeness in characteristics with respect to TSP concentrations.

The MU locations did not show trends as observed in the case of MP locations (Fig. 3.11). The minimum TSP concentration of $120.5 \mu\text{gm}^{-3}$ was observed at MU5 location (main bus terminus, one way traffic) and the maximum TSP of $496.4 \mu\text{gm}^{-3}$ at MU10 (highway). The peak value of $597.2 \mu\text{gm}^{-3}$ was observed at MU3 (commercial place with medium and high rise buildings). In general, MU locations had TSP values of $400 \mu\text{gm}^{-3}$ excluding MU5 location that showed lower concentrations. The ambient air quality at MU locations was “high” at MU5 (1.2S)

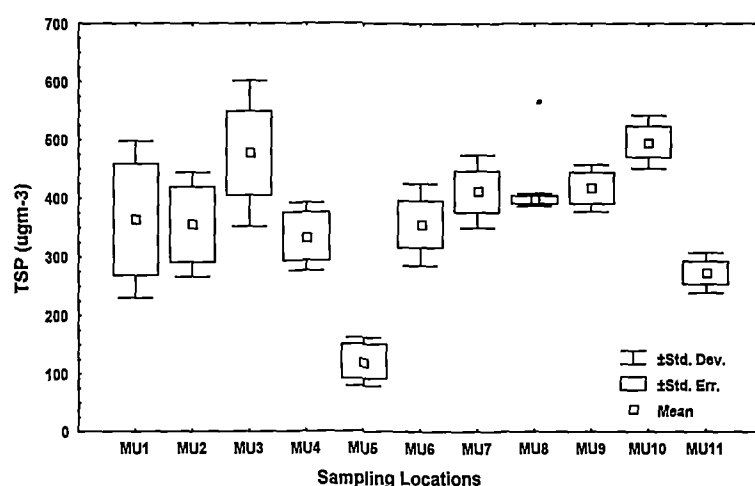


Fig. 3.11 Temporal variations in TSP at MU locations

while “critical” at rest of the locations as TSP/NAAQS ratio ranged between 3.3S to 5.0S. The clustering of MU locations is shown by hierarchical plot (Fig. 3.12). It

was observed that except the MU5 location, which was the “State Bus Terminus” with one way traffic system, the rest of the MU locations could be grouped within a Euclidean distance of about 120. The characteristics of MU5 location differed due to

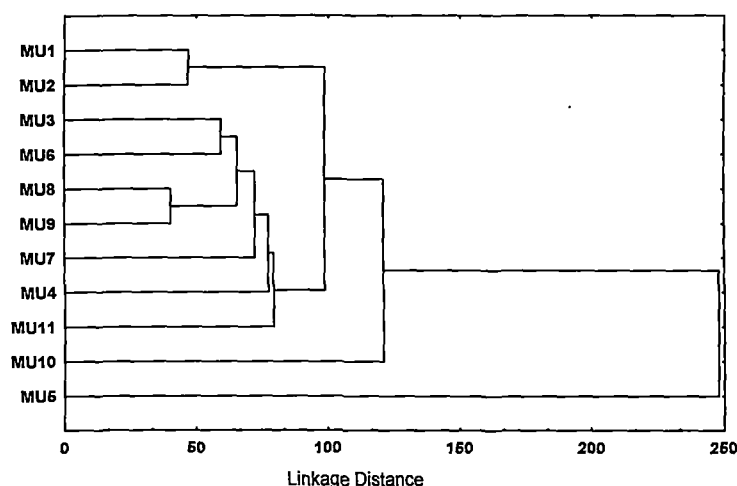


Fig. 3.12 Hierarchical plot of TSP for MU locations

its one-way traffic system as the vehicles were allowed only to move from high gradient towards the slope. This also showed considerable closeness of MU locations with each other with respect to the TSP concentrations.

The HP locations did not show trends as observed in the case of MP locations (Fig. 3.13). The minimum TSP concentration of $169.5 \mu\text{gm}^{-3}$ was observed at HP5 location (a hospital near commercial area) and the maximum TSP concentration of $491.7 \mu\text{gm}^{-3}$ was obtained at HP9 (the busiest traffic density of Dhankheti). The peak value of $508.3 \mu\text{gm}^{-3}$ was also observed at HP9. The ambient air quality at all the HP locations was “critical” as TSP/NAAQS ratio ranged between 1.7S to 4.9S. The clustering of HP locations is shown by hierarchical plot

(Fig. 3.14). A better closeness in comparison with the MP and MU locations was observed within the category of HP locations as all the locations had been grouped within a Euclidean distance of about 150.

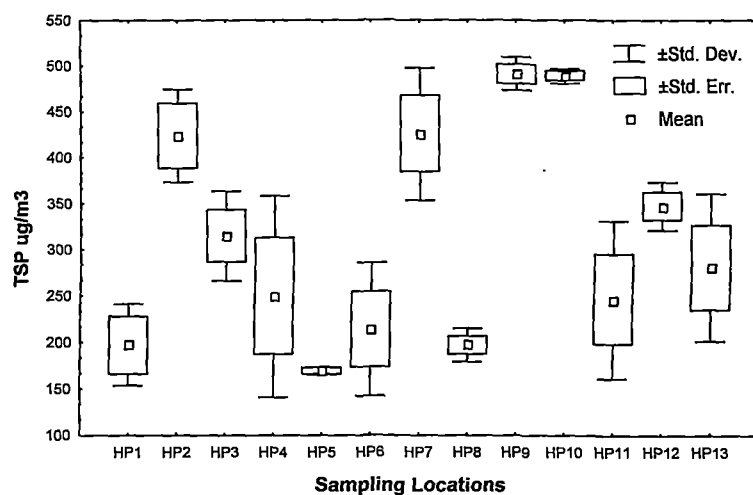


Fig. 3.13 Temporal variations in TSP at HP locations

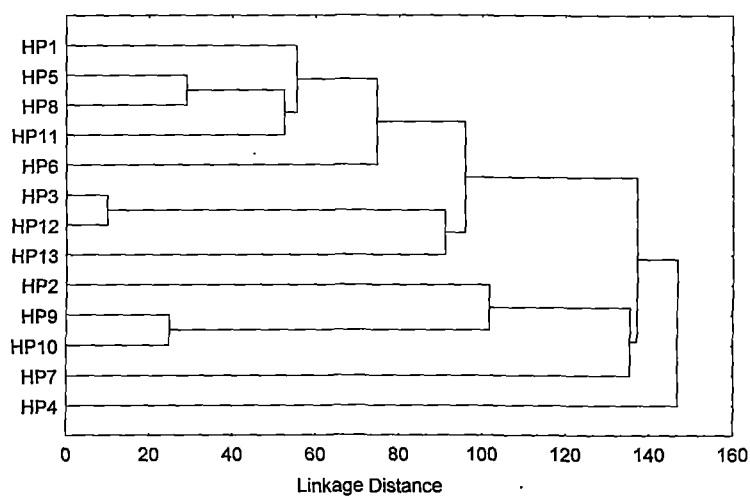


Fig. 3.14 Hierarchical plot of TSP for HP locations

At HU locations (Fig. 3.15), the TSP concentrations showed increasing trends from HU1 ($291.7 \mu\text{gm}^{-3}$) up to HU5 ($664.3 \mu\text{gm}^{-3}$), a busy commercial area

surrounded by medium height buildings, then it dropped at HU6 (near state assembly, one way traffic) to $183.5 \mu\text{gm}^{-3}$. The similar increasing trend was observed again up to HU10 where it reached $590.4 \mu\text{gm}^{-3}$. The peak value of $854.0 \mu\text{gm}^{-3}$ was also observed at HU5. The ambient air quality at all the HU locations was “critical” as TSP/NAAQS ratio ranged between 1.8S at HU6 location to 6.6S at HU5 location. The clustering of HU locations is shown by hierarchical plot (Fig.

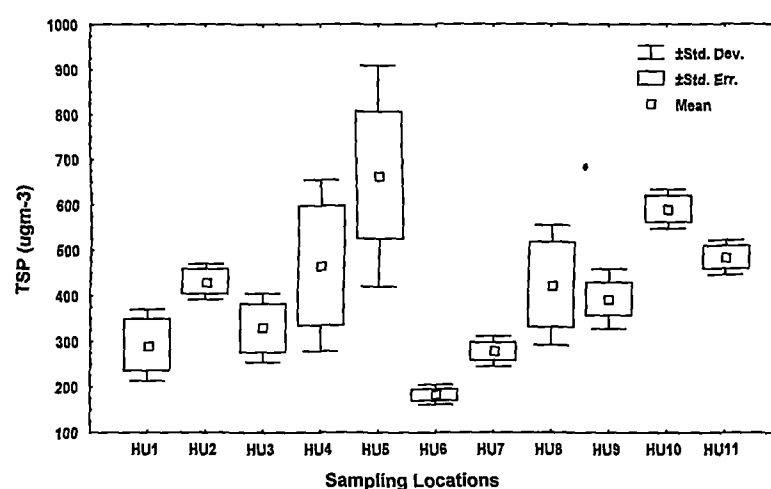


Fig. 3.15 Temporal variations in TSP at HU locations

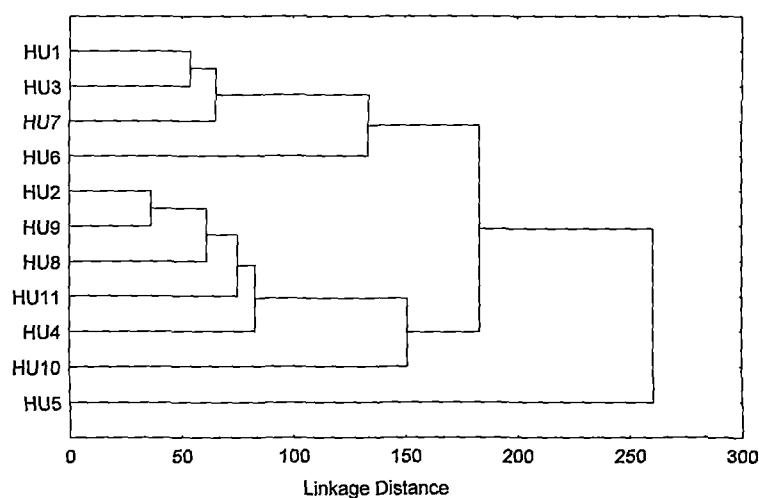


Fig. 3.16 Hierarchical plot of TSP for HU locations

3.16). Two distinct groups could be seen in the plot that had been grouped within the Euclidean distance of less than 200. The road gradient played an important role in mass loadings because Euclidean distance of about 260 was required to group HU5 location showing considerable diversity with rest of the HU locations.

At TIF locations (Fig. 3.17), the TSP concentrations showed decreasing trends in across direction locations both north and south from the highway. At TIF0 location, the TSP concentration was $449.1 \mu\text{g m}^{-3}$ which dropped to $132.5 \mu\text{g m}^{-3}$ at TIFN1 and to $169.5 \mu\text{g m}^{-3}$ at TIFS1 locations thus recording a drop of 70% and 62% respectively just after a distance of about 300 meters from highway. The TSP concentrations at TIFN2 and TIFS2 recorded further decrease of 23% and 27% in TSP with respect to TIFN1 and TIFS1 locations. TIFN3 and TIFS3 again showed a

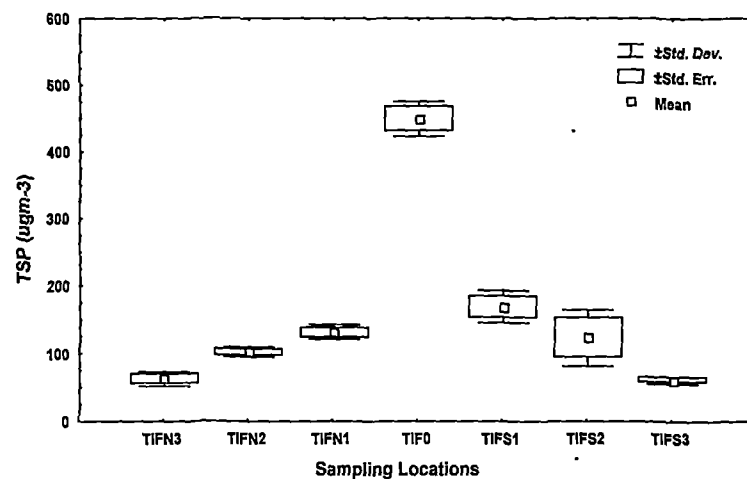


Fig. 3.17 Temporal variations in TSP at TIF locations

drop of 39% and 50% respectively in comparison with TIFN2 and TIFS2 locations. The considerably low TSP concentrations at TIFN3 and TIFS3 locations, however,

indicated fast TSP dispersion perhaps due to the persistent turbulent atmospheric conditions in the city that facilitated better dispersion. The high TSP concentrations at the traffic intersection and then sudden but gradual decrease in its concentration at across locations were clear indications that TSP concentration shoots up mainly due to vehicular emissions at the breathing level near traffic activity zones. WHO also believes that vehicles emit pollutants in close proximity to the breathing zone of the people and, therefore, find it necessary to consider the localized as well as general effects on the atmosphere (WHO, 1969). Our findings were in accordance with that of Nitta *et al.* (1993), who conducted measurements of TSP at different distances from a busy road in Tokyo, Japan and observed decline in mean TSP concentrations from $77 \mu\text{gm}^{-3}$ to $64 \mu\text{gm}^{-3}$ at 150 meter distance showing a drop of about 17%. The measurements from the North Rhine-Westphalia air quality network in Germany also observed the 27% higher TSP concentrations at a busy traffic junction of Dusseldorf in comparison with stations not directly influenced by the traffic (Pfeffer, 1994). The ambient air quality at TIF0 location was “critical” (4.5S) while it was “high” at TIFN1 (1.3S), TIFS1 (1.7S) and TIFS2 (1.2S). The air quality at TIFN3 (0.6S), TIFN2 (1.0S) and TIFS3 (0.6) was “moderate”. The clustering of TIF locations is shown by hierarchical plot (Fig. 3.18). It was observed that except the TIF0 location, which had been situated on highway, the rest of the locations had been grouped within a Euclidean distance of about 56. To group the TIF0 location the Euclidean distance was as high as 395 showing marked dissimilarities with the across locations.

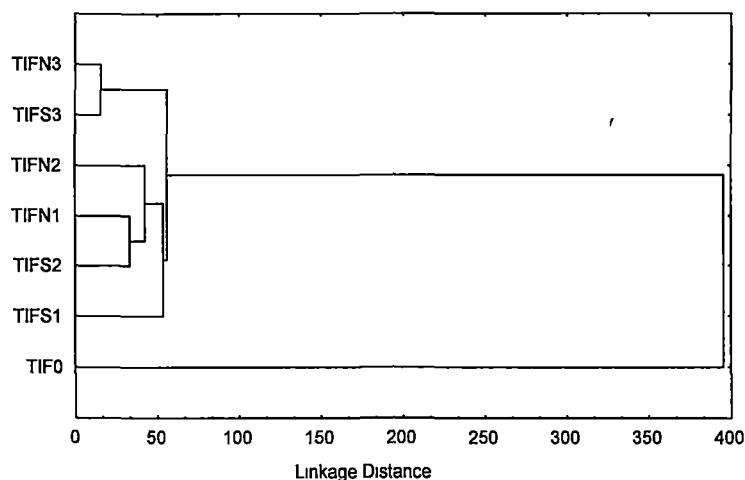


Fig. 3.18 Hierarchical plot of TSP for TIF locations

At TIB locations (Fig. 3.19), the TSP concentrations also showed similar decreasing trends at all locations situated in across directions of both north and south from highway as was observed at TIF locations. At TIB0 location, the TSP concentration was $198.6 \mu\text{gm}^{-3}$, which dropped to $130.4 \mu\text{gm}^{-3}$ at TIBN1 and to $137.1 \mu\text{gm}^{-3}$ at TIBS1 locations thus recording a drop in TSP of 34% and 31% respectively. The TSP concentrations at TIBN2 and TIBS2 recorded a decrease of 12% and 34% in TSP with respect to TIBN1 and TIBS1 locations. TIBN3 and TIBS3 showed a further drop of 28% in comparison with TIBN2 and TIBS2 locations. Thus TSP concentrations at this intersection also showed similar sudden but gradual decrease at across locations. The ambient air quality at TIB0 location was “critical” (2.0S) while it was “high” at TIBN1 (1.3S), TIBS1 (1.4S) and TIBN2 (1.1S). The air quality at TIBN3 (0.6S), TIBS2 (0.9S) and TIBS3 (0.8) was “moderate”. The clustering of TIB locations is shown by hierarchical plot (Fig. 3.20). It was observed that except the TIB0 location, which was situated on

highway, the rest of the locations had been grouped within a Euclidean distance of about 50. The TIB locations did not show the vast difference as was observed in the case of TIF locations. TIB0 was a busy location on the highway with significant open space that perhaps checked build up of the pollution concentration in the area and facilitated its faster dispersion.

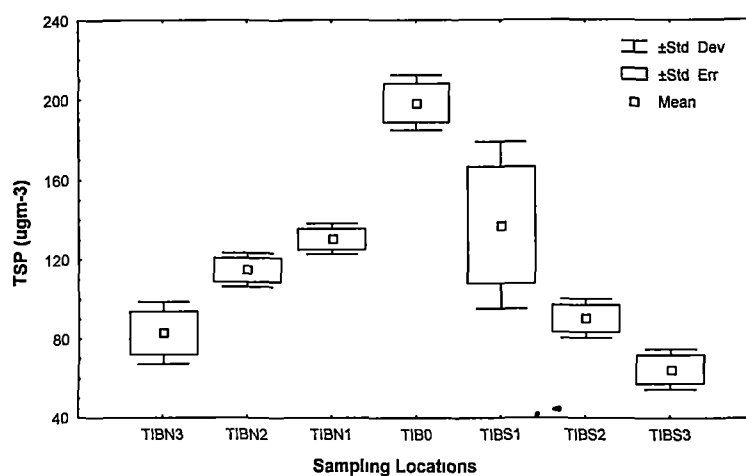


Fig. 3.19 Temporal variations in TSP at TIB locations

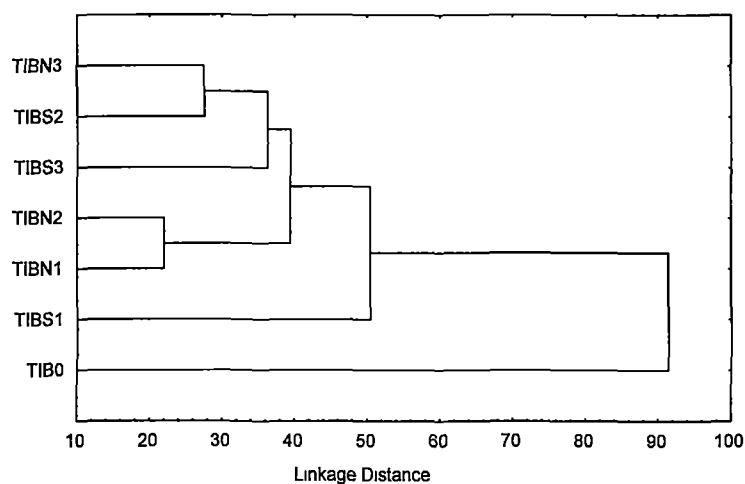


Fig. 3.20 Hierarchical plot of TSP for TIB locations

At TIG intersection (Fig. 3.21), the TSP concentrations also showed similar decreasing trends at all locations situated in across directions. At TIG0 location, the TSP concentration was $581.7 \mu\text{gm}^{-3}$, which dropped to $232.5 \mu\text{gm}^{-3}$ at TIGN1 and to $152.8 \mu\text{gm}^{-3}$ at TIGS1 locations thus recording a drop of 60% and 75% respectively. TSP at TIGN2 and TIGS2 showed further decrease of 33% and 9% with respect to TIGN1 and TIGS1 locations. TIGN3 and TIGS3 recorded a drop of 35% and 15% respectively in comparison with TIGN2 and TIGS2 locations. Thus TSP concentrations at TIG locations also showed similar characteristic of sudden but gradual decrease in concentration at across locations as was observed in the case of TIF and TIB intersections. The ambient air quality at TIG0, TIGN1 and TIGN2 locations was “critical” as TSP/NAAQS ratios were 5.8S, 2.3S and 1.6S respectively while it was “high” at TIGS1 (1.4S), TIGS2 (1.3S) and TIGS3 (1.1S). The air quality at TIGN3 (1.0S) was “moderate”. The clustering of TIG locations is shown by hierarchical plot (Fig. 3.22). It was observed that up to the Euclidean

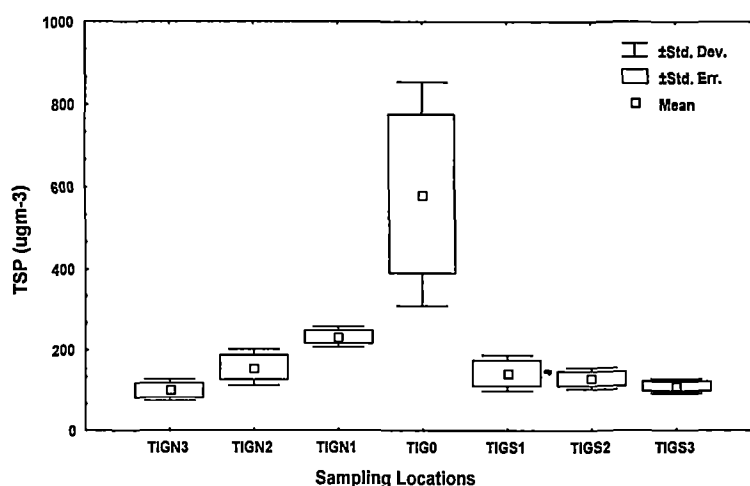


Fig. 3.21 Temporal variations in TSP at TIG locations

distance of about 30, only 5 locations were grouped. To group TIG0 location on highway, the Euclidean distance became as high as 576, which explicitly indicated vast difference with its across locations.

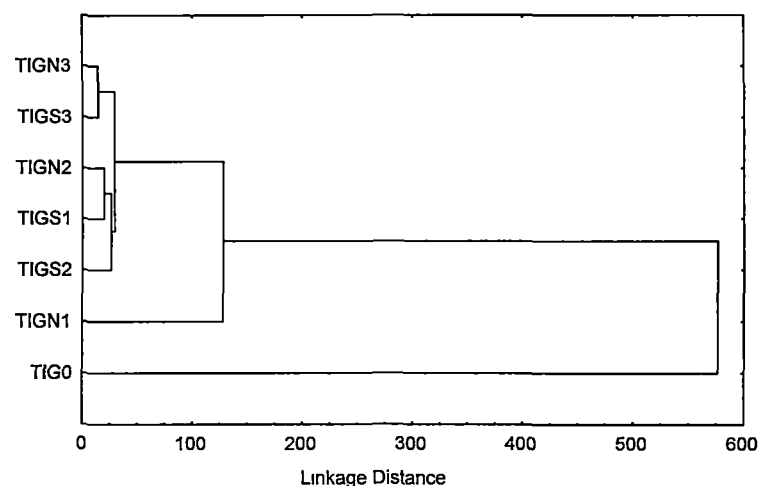


Fig. 3.22 Hierarchical plot of TSP for TIG locations

TSP concentrations at H1 and H2 locations were $383.2 \mu\text{gm}^{-3}$ and $217.5 \mu\text{gm}^{-3}$ while it was $96.1 \mu\text{gm}^{-3}$ and $84.5 \mu\text{gm}^{-3}$ at IN1 and IN2 locations respectively. The drop in TSP values from H1 to IN1 was about 4 times while H2 to IN2 it was 2.6 times. Air quality was “critical” at H1 and H2 as TSP/NAAQS ratio were 3.8S and 2.2S respectively and was “moderate” at IN1 and IN2 (1.0S and 0.8S respectively). The Euclidian between H1 and H2 was 256.0 and between IN1 and IN2 was 23.8 that indicated the closeness of indoor atmospheric conditions.

The TSP concentrations at IE locations showed quite diverse trends. The TSP concentrations at IE1 and IE2 locations were $236.1 \mu\text{gm}^{-3}$ and $825.3 \mu\text{gm}^{-3}$ respectively with a peak value of $928.3 \mu\text{gm}^{-3}$ at IE2 location. The difference in TSP

concentrations between IE1 and IE2 location was more than 3 times. Air quality was “critical” at both IE1 and IE2 as TSP/NAAQS ratios were 2.4S and 8.3S. The Euclidian distance between IE1 and IE2 was 842.6 indicating enormous difference in characteristics though both fell under “critical” category.

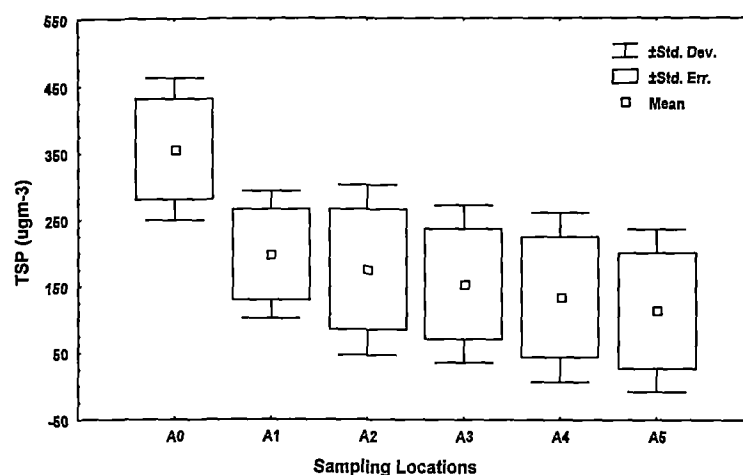


Fig. 3.23 Temporal variations in TSP at A locations

At A locations (Fig. 3.23), TSP showed decreasing trends from ground level (A0) up to the rooftop (A5). The TSP concentrations at A0, A1, A2, A3, A4 and A5 were $355.3 \mu\text{gm}^{-3}$, $196.0 \mu\text{gm}^{-3}$, $173.6 \mu\text{gm}^{-3}$, $152.8 \mu\text{gm}^{-3}$, $132.7 \mu\text{gm}^{-3}$ and $112.7 \mu\text{gm}^{-3}$ respectively showing decrease of 45%, 11%, 12%, 13% and 15% from the nearest location from the ground level to upward direction. Though the drop in TSP concentration from A0 to A5 location was about 3 times but the air quality at A0, A1, A2 and A3 was “critical” as TSP/NAAQS ratios were 3.6S, 2.0S, 1.7S and 1.5S respectively. The air quality at A4 and A5 locations was “moderate” (1.3S and 1.1S respectively). The clustering of A locations is shown by hierarchical plot (Fig. 3.24).

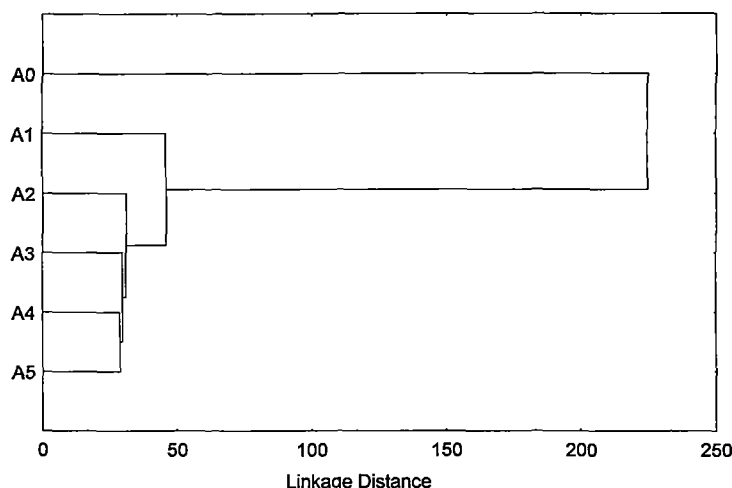


Fig. 3.24 Hierarchical plot of TSP for A locations

A very clear picture emerged from the cluster analysis of these locations as locations were grouped from the rooftop of A5 to the bottom floor of A0. Except A0, the Euclidean distance of 46 could group rest of the locations. The A0 showed marked dissimilarities with the other locations at various elevations because to group these locations, the Euclidean distance became as high as 225.

3.4.4 Relationship of TSP with traffic density

Traffic and its associated activities along the highways and major arterial roads were the key source of air pollutants build-up at breathing zone in the atmosphere of Shillong. Attempts were made to obtain the linear relationships of mean TSP concentrations (Appendix-III, Tables A.3. 15 to A.3.18) with the average traffic density (Appendix-I, Tables A.1.1 to A.1.4) at MP, MU, HP and HU locations by drawing least-square regression lines as these locations had shown definite traffic patterns. Pearson correlation coefficients between mean TSP

concentrations and traffic density and pair-wise correlations between MP, MU, HP and HU locations on the basis of TSP were also calculated.

The relationship of TSP with TW, LV, HV and ρ_T (Fig. 3.25 a, b, c & d) at MP locations could be represented in the form of the following mathematical equations:

$$\text{TSP (MP)} = 0.1026 * \text{TW} + 256.69 \quad (3.1)$$

$$\text{TSP (MP)} = 0.1233 * \text{LV} + 118.13 \quad (3.2)$$

$$\text{TSP (MP)} = -0.0934 * \text{HV} + 330.95 \quad (3.3)$$

$$\text{TSP (MP)} = 0.0447 * \rho_T + 182.97 \quad (3.4)$$

TW showed positive relationship with TSP but the scattered points on both sides of the least-square regression line (Fig. 3.25a) indicated inconsistency in the affiliation (Eq. 3.1). The correlation coefficient (R^2) for TW and TSP was very low (0.01) indicating small contribution of TW to particulate mass loadings. The relationship of LVs with TSP (Fig. 3.25b) was also positive (Eq. 3.2). LVs had shown comparatively strong relationship, as the correlation coefficient (R^2) for LV and TSP was high (0.42). It suggested that 42% of variance in TSP concentrations at MP locations could be explained by LV density. HV had shown negative relationship (Eq. 3.3) with TSP (Fig. 3.25c). The correlation coefficient (R^2) for HV and TSP was low (0.09). The relationship of ρ_T with TSP (Fig. 3.25d) was also positive (Eq. 3.4). The correlation coefficient (R^2) for ρ_T with TSP was low (0.10) suggesting that total traffic density could explain 10% variations in TSP concentrations at MP locations. The Pearson correlations (Table 3.5) also confirmed the relationship of various types of vehicle density with TSP at MP locations. The correlation of TW

with TSP was positive but weak (0.11). The LV had positive (0.65*) and significant ($p < 0.05$) correlation with TSP. The HV had negative correlation (-0.30) while the ρ_T showed moderate correlation of 0.35 with the TSP concentrations at MP locations.

Table 3.5 Pearson correlation coefficients of TSP with traffic density				
Location	TW	LV	HV	PT
MP	0.11	0.65*	-0.30	0.35
MU	0.10	0.29	-0.43	0.38
HP	0.51	0.32	0.66*	0.46
HU	-0.28	-0.16	0.53	-0.10

At MU locations, the relationship of TSP with TW, LV, HV and ρ_T (Fig.

3.26 a, b, c & d) could be represented by the following mathematical equations:

$$\text{TSP (MU)} = 0.0555 * \text{TW} + 348.4 \quad (3.5)$$

$$\text{TSP (MU)} = 0.0345 * \text{LV} + 315.99 \quad (3.6)$$

$$\text{TSP (MU)} = 0.1488 * \text{HV} + 268.15 \quad (3.7)$$

$$\text{TSP (MU)} = 0.0367 * \rho_T + 279.29 \quad (3.8)$$

TW showed positive relationship with TSP but the inconsistency in the affiliation (Eq. 3.5) was quite pronounced as the scattered points on both sides of the least-square regression line could be observed as were seen in the case of MP locations (Fig. 3.26a). The correlation coefficient (R^2) for TW and TSP was also very low (0.01). The relationship of LVs with TSP (Fig. 3.26b) was also positive (Eq. 3.6). The relationship of LV with TSP at these locations was not as high as observed in the case of MP locations, as the correlation coefficient (R^2) for LV with TSP was 0.09. It implied that only 9% of the variance in TSP concentrations at MU locations could be explained by LV density. Contrary to the observations made at MP

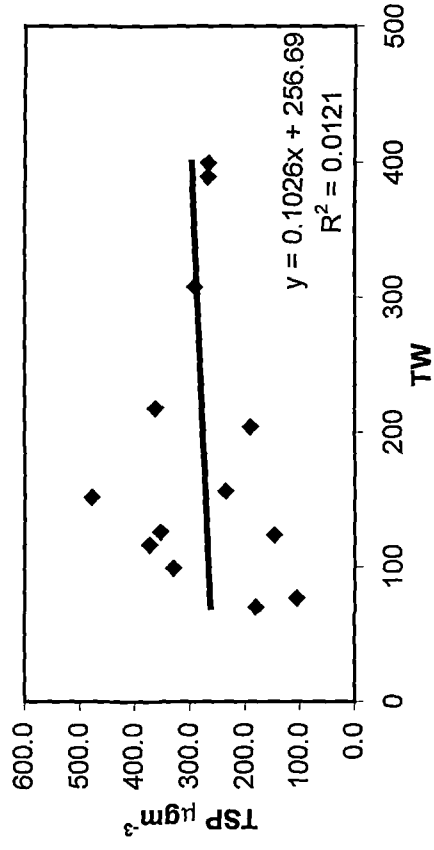


Fig. 3.25a Relationship of TSP with TW at MP locations

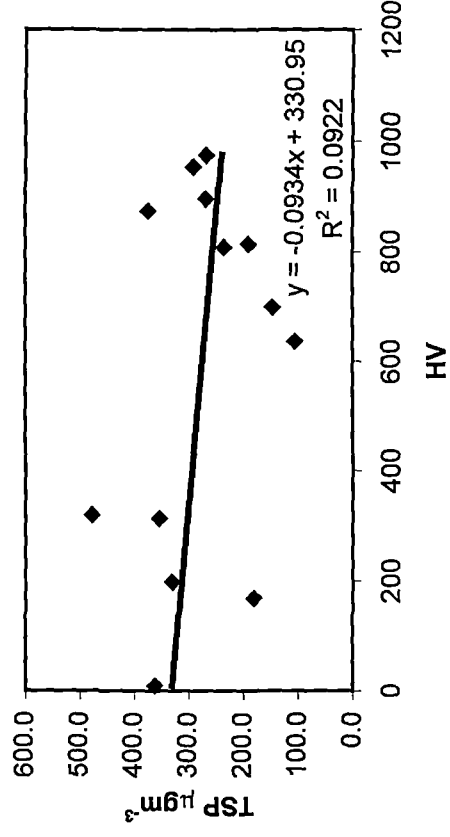


Fig. 3.25c Relationship of TSP with HV at MP locations

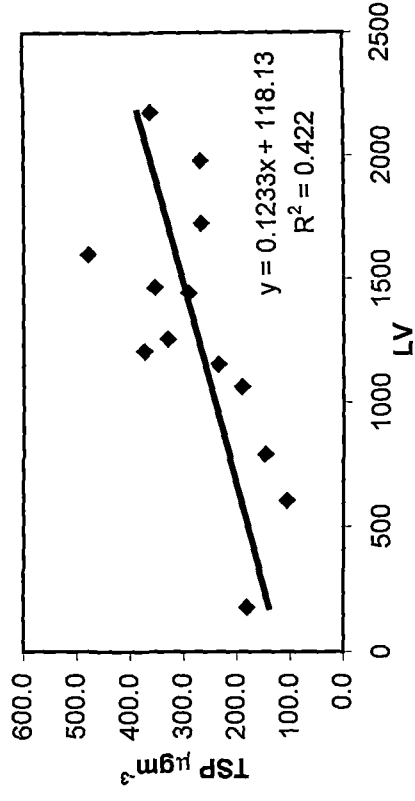


Fig. 3.25b Relationship of TSP with LV at MP locations

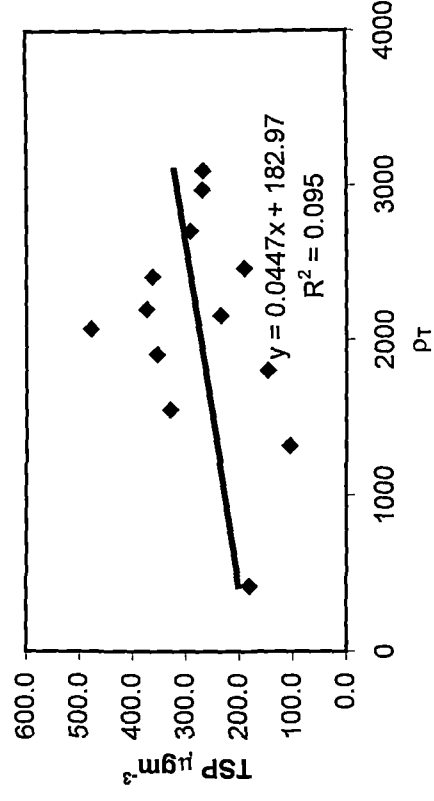


Fig. 3.25d Relationship of TSP with ρ_T at MP locations

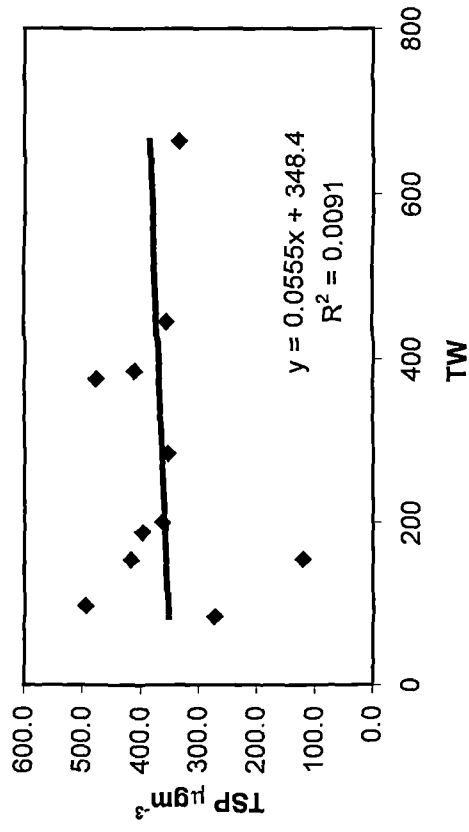


Fig. 3.26a Relationship of TSP with TW at MU locations

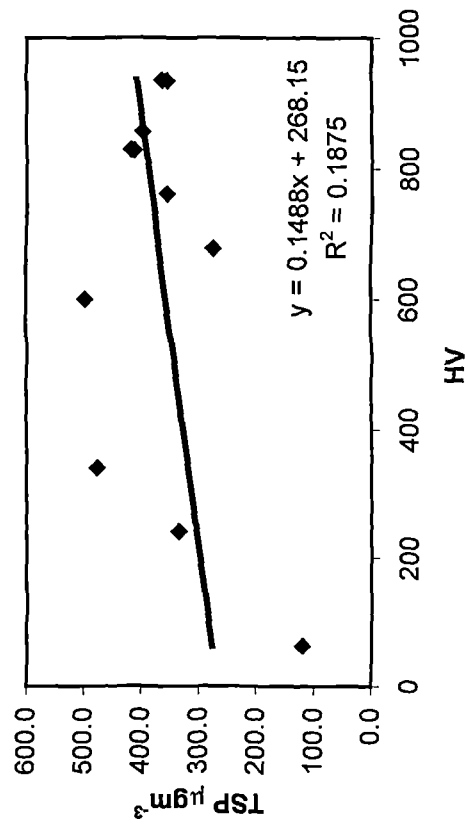


Fig. 3.26c Relationship of TSP with HV at MU locations

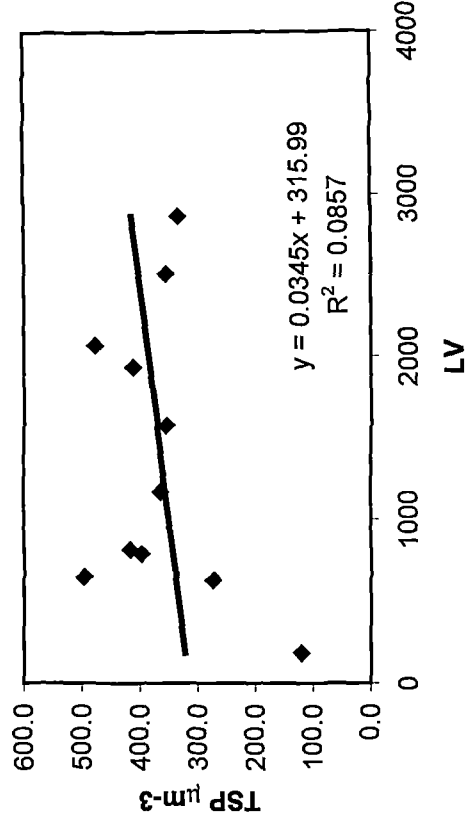


Fig. 3.26b Relationship of TSP with LV at MU locations

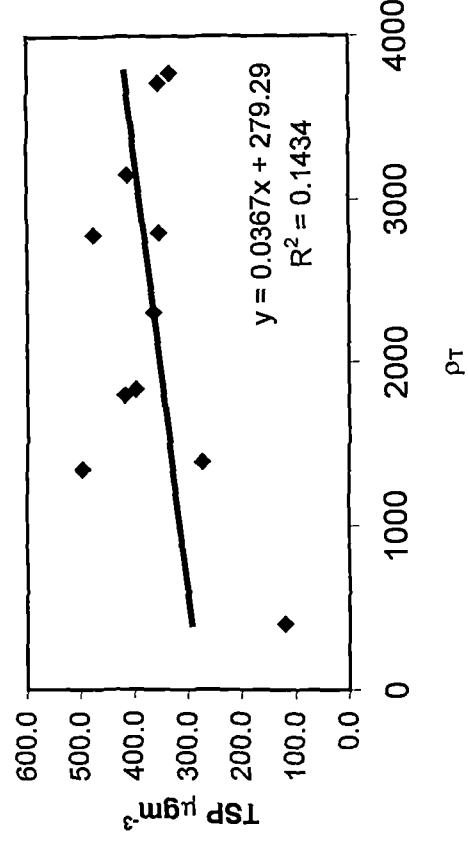


Fig. 3.26d Relationship of TSP with ρ_T at MU locations

locations, the relationship of HV with TSP (Fig. 3.26c) was positive (Eq. 3.7). The correlation coefficient (R^2) for HV and TSP was 0.19. This signified the change in emission characteristics of diesel powered heavy vehicles at steep gradient roads with a bias towards emission of considerably more particulate mass. The relationship of ρ_T with TSP (Fig. 3.26d) was also positive (Eq. 3.8). The correlation coefficient (R^2) for ρ_T with TSP was 0.14 suggesting that total traffic density could explain 14% variations in TSP concentrations at MU locations, which was stronger in comparison with that obtained for MP locations. The Pearson correlations (Table 3.5) also corroborated the relationship of various types of traffic density with the TSP concentrations at MU locations. The correlation of TW with TSP was positive and weak (0.10) while LV had a positive (0.29) correlation. The HV showed positive correlation (0.43) whereas ρ_T showed correlation of 0.38 with the TSP concentrations at MU locations.

The relationship of TSP with TW, LV, HV and ρ_T (Fig. 3.27 a, b, c & d) at HP locations could be represented in the form of the following mathematical equations:

$$\text{TSP (HP)} = 0.1945 * \text{TW} + 133.15 \quad (3.9)$$

$$\text{TSP (HP)} = 0.0334 * \text{LV} + 167.36 \quad (3.10)$$

$$\text{TSP (HP)} = 0.1873 * \text{HV} + 176.83 \quad (3.11)$$

$$\text{TSP (HP)} = 0.0319 * \rho_T + 121.84 \quad (3.12)$$

The relationship of TW with TSP was positive (Eq. 3.9). The TW had shown stronger association at HP locations in comparison with the MP and MU locations (Fig. 3.27a). The correlation coefficient (R^2) for TW and TSP was also

comparatively high (0.28). The relationship of LVs with TSP (Fig. 3.27b) was also positive (Eq 3.10). The relationship of LV with TSP at these locations was not as high as was observed in the case of MP locations, as the correlation coefficient (R^2) for LV with TSP was 0.15. The relationship of HV with TSP (Fig. 3.27c) was significantly positive (Eq. 3.11). The correlation coefficient (R^2) for HV and TSP was 0.40. The relationship of ρ_T with TSP (Fig 3.27d) was also positive (Eq. 3.12). The correlation coefficient (R^2) for ρ_T with TSP was 0.26 suggesting that total traffic density could explain 26% variations in TSP concentrations at HP locations. The Pearson correlations (Table 3.5) also corroborated the association of various types of traffic density with the TSP concentrations at HP locations. The correlation of TW with TSP was positive and significant (0.51) while LV had a positive (0.32) correlation. The HV showed positive (0.66*) and significant correlation ($p < 0.05$) whereas ρ_T showed correlation of 0.46 with the TSP concentrations at HP locations.

The relationship of TSP with TW, LV, HV and ρ_T (Fig. 3.28 a, b, c & d) at HU locations could be represented in the form of the following mathematical equations:

$$\text{TSP (HU)} = -0.1318 * \text{TW} + 536.26 \quad (3.13)$$

$$\text{TSP (HU)} = -0.0208 * \text{LV} + 497.47 \quad (3.14)$$

$$\text{TSP (HU)} = 0.3056 * \text{HV} + 67.46 \quad (3.15)$$

$$\text{TSP (HU)} = -0.011 * \rho_T + 479.97 \quad (3.16)$$

Contrary to the expectations, the TW, LV and ρ_T demonstrated negative relationships with TSP though HV had shown significantly positive association (Eq. 3.13 to 3.16). The correlation coefficient (R^2) for HV and TSP was 0.28 indicating

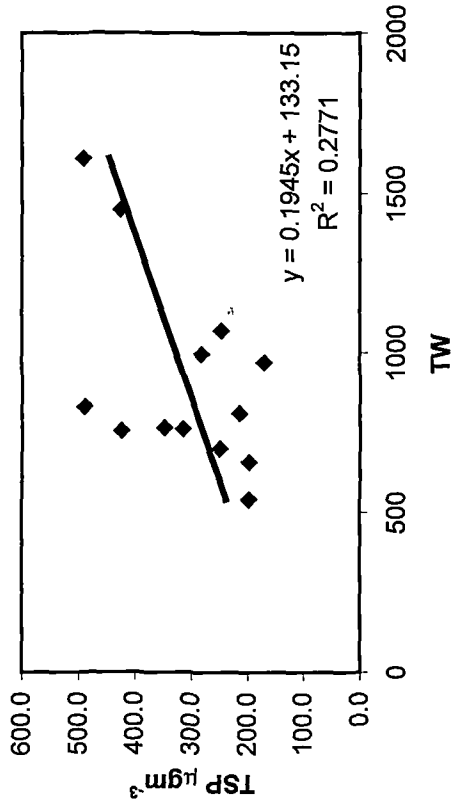


Fig. 3.27a Relationship of TSP with TW at HP locations

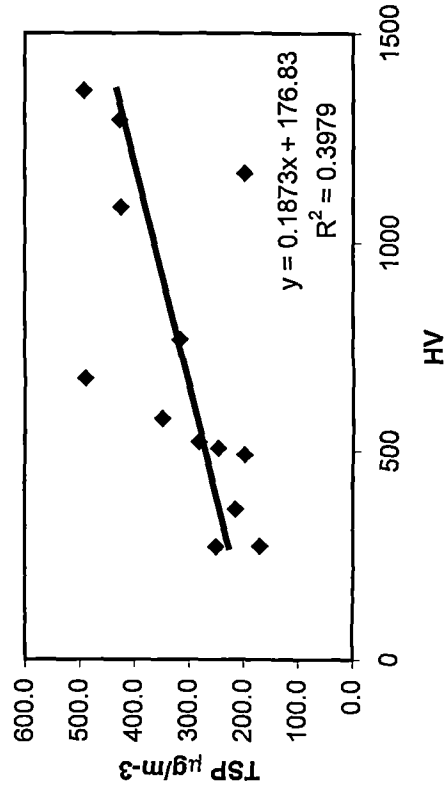


Fig. 3.27c Relationship of TSP with HV at HP locations

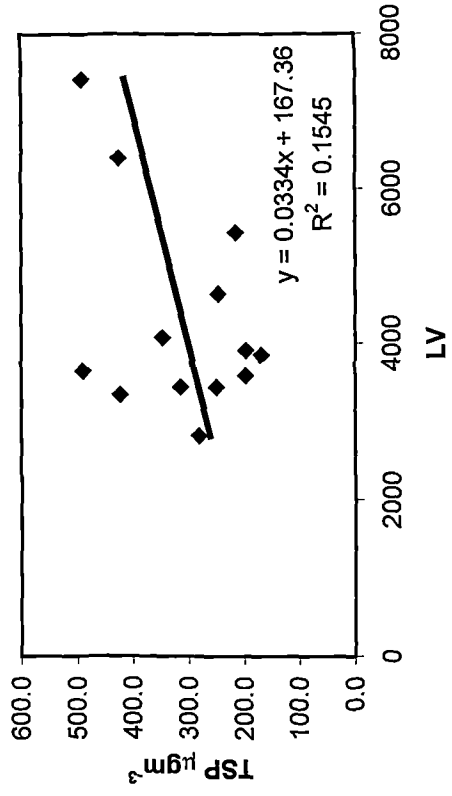


Fig. 3.27b Relationship of TSP with LV at HP locations

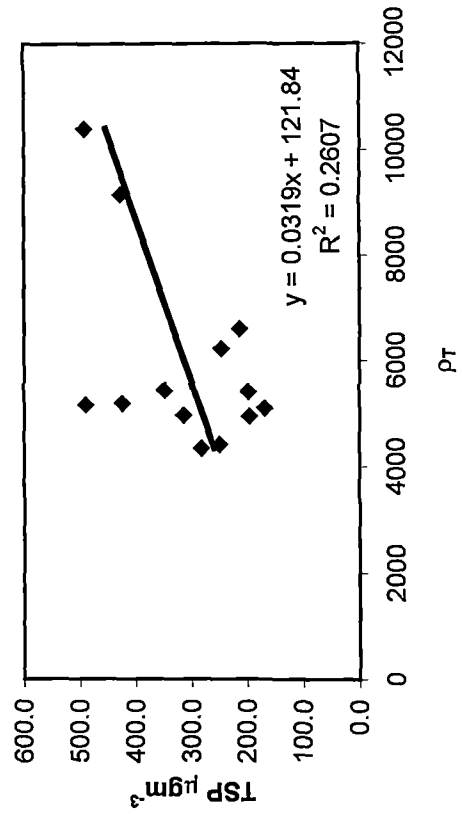


Fig. 3.27d Relationship of TSP with ρ_T at HP locations

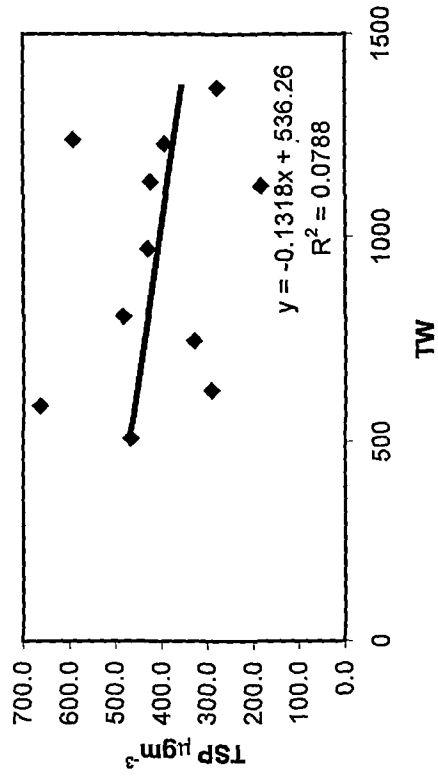


Fig. 3.28a Relationship of TSP with TW at HU locations

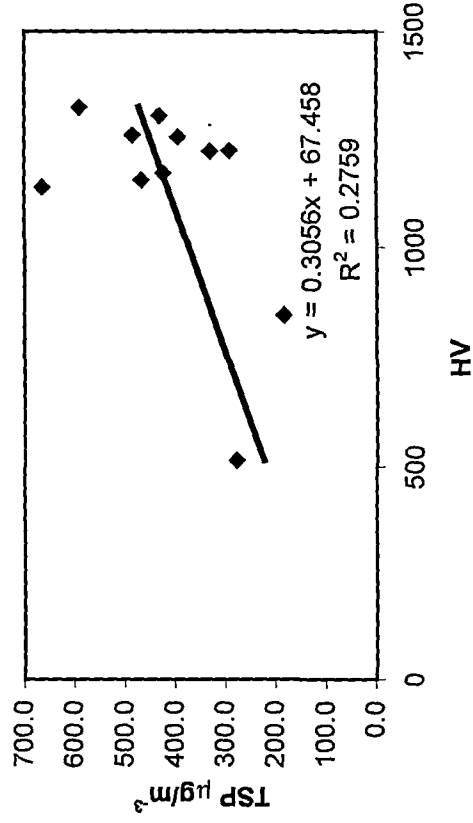


Fig. 3.28c Relationship of TSP with HV at HU locations

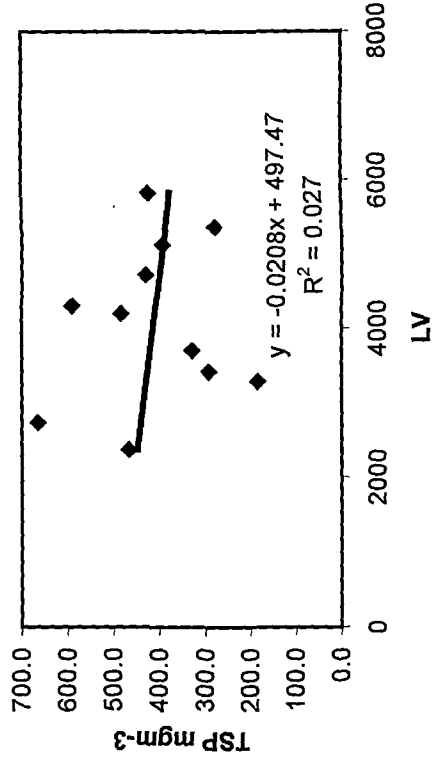


Fig. 3.28b Relationship of TSP with LV at HU locations

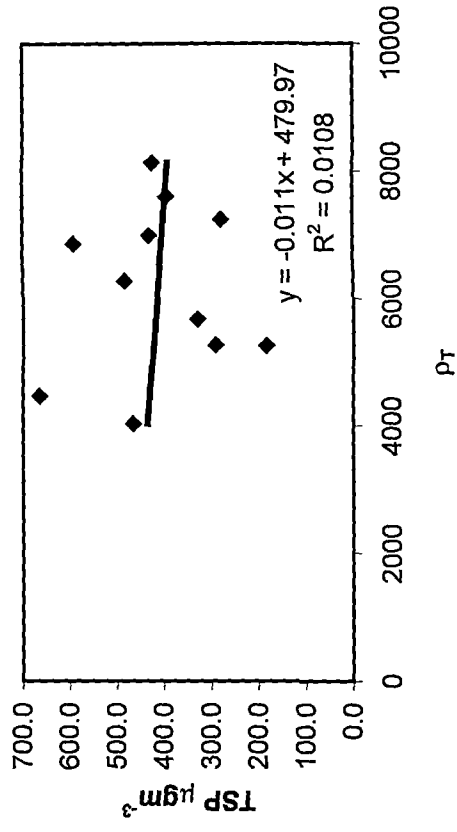


Fig. 3.28d Relationship of TSP with PT at HU locations

that HV density could explain 28% of the TSP variations at HU locations. The Pearson correlations (Table 3.5) also confirmed the relationship of various types of traffic density with the TSP concentrations at MP locations. The correlation of TW with TSP was negative and weak (-0.28). The LV has a correlation of -0.16 with TSP. The HV had high positive correlation (0.53) while ρ_T showed negative correlation of -0.10 with the TSP concentrations at HU locations.

Roorda-Knape *et al.* (1998) had conducted a study to establish correlations of traffic density with various pollutants including the particulate matter in South Holland, Netherlands. They found correlations of -0.17 with heavy vehicles, -0.04 with cars and -0.07 with total traffic density. In case of heavy vehicles and cars they got significant correlation ($P < 0.10$). Our findings were in agreement with the results of that study.

In order to gain an idea of the relationship between the four categories of MP, MU, HP and HU locations, the correlation analysis was carried out using the cumulative mean TSP concentrations (Table 3.6). Correlations showed that MP locations were closely related with MU ($r=0.97$) and HU locations ($r=0.67$) but had negative correlation with HP locations ($r=-0.40$). Perhaps due to thin traffic density at MP locations, the traffic speed was generally high but to negotiate the high road gradients of MU and HU locations, the vehicles operated on high load conditions.

Table 3.6 Pairwise correlation between MP, MU, HP and HU locations				
Location	MP	MU	HP	HU
MP	1.00	0.97	-0.40	0.67
MU		1.00	-0.62	0.47
HP			1.00	0.41
HU				1.00

The similarity in use of accelerated vehicle speeds possibly provided stronger correlations between these locations because vehicles were a major source of elevated TSP levels at breathing level in Shillong. The MU locations had negative correlation with HP locations ($r=-0.62$) but showed positive correlation with HU ($r=0.47$) due to similarities between MU and HU locations in the topographical characteristics. Correlation of HP with HU was positive ($r=0.41$) which was understandable due to their closeness in traffic densities.

3.4.5 Relationship of TSP with meteorological variables

Several workers have studied effects of meteorological variables such as wind speed (WS), wind direction (WD) and relative humidity (RH) (Leung *et al.*, 1993; Monn *et al.*, 1995) on ambient TSP concentrations. We had also obtained correlations of TSP with ambient temperature, WD, WS and RH for the CB, MP, MU, HP and HU locations (Table 3.7). TSP showed positive correlations with ambient temperature at MU ($r=0.61$, $p<0.05$) and HP ($r=0.09$) and negative at CB ($r=-0.99$), MP ($r=-0.37$) and HU ($r=-0.18$). The positive correlations of TSP with WD were observed at CB ($r=0.85$) and HU ($r=0.14$) while negative correlations were seen at MP ($r=-0.24$), MU ($r=-0.56$) and HP ($r=-0.50$). TSP showed positive correlations with WS at MP ($r=0.05$), MU ($r=0.41$), HP ($r=0.30$), HU ($r=0.03$), and negative at CB ($r=-0.99$). The positive correlations of TSP with RH were observed at CB ($r=0.99$) and MU ($r=0.16$) while negative correlations were seen at MP ($r=-0.30$), HP ($r=-0.58$) and HU ($r=-0.16$). The negative relationship of TSP with ambient temperature showed its inverse behaviour with TSP. In general, meteorological

variables did not show definite correlation patterns. It was quite agreeable as the build up of mass concentration at a particular location depended on factors such as mechanical turbulence created by the moving vehicles and the wind, the thermal turbulence induced by the hot vehicular exhaust gases. The approaching wind also produces dilution effects and in street canyon configuration, a traverse wind across the street would create re-circulation and increase the pollutant concentration.

Table 3.7 Correlations of TSP with meteorological variables				
Location	Amb Temp	WD	WS	RH
CB	-0.99	0.85	-0.99	0.99
MP	-0.37	-0.24	0.05	-0.30
MU	0.61*	-0.56	0.41	0.16
HP	0.09	-0.50	0.30	-0.58
HU	-0.18	0.14	0.03	-0.16

* Significant correlation ($P < 0.05$)

Our findings were similar with that observed by Lam, *et al.* (1999) for certain categories of locations for TSP with WS (0.49) and RH (0.11) and are in accordance with that of Monn *et al.* (1995), who had observed relationship of particulate matter with ambient temp ($r = -0.29$ to -0.65), RH ($r = -0.57$ to 0.24) and WS ($r = -0.13$ to -0.34).

The influence of meteorological variables on TSP concentrations in Shillong had been found to be of diminutive consequence perhaps due to relatively small variations in meteorological conditions between one sampling to another.

3.4.6 Soot concentrations in TSP

The discussion on soot has been divided into three sub-sections. In sub-

section 3.4.6, we have discussed the variations in soot concentrations at all the categories of sampling locations. This sub-section also includes discussions on TSP/soot ratios. The linear relationship of soot with TSP and Pearson correlation coefficients constitute sub-section 3.4.7. The correlations of soot with traffic density are dealt in sub-section 3.4.8.

Soot concentrations obtained for various categories of sampling locations have been given in the form of the bar graphs (Fig. 3.29 to 3.36). No soot was detected at CB locations. The soot concentration at MP locations (Fig. 3.29) varied from $26.9 \mu\text{gm}^{-3}$ at MP1 location (the entrance point to city in north) to $142.9 \mu\text{gm}^{-3}$ at MP8 location (the busiest commercial area with a bus stand). The mean soot concentration at MP location was $76.7 \mu\text{gm}^{-3}$. MU locations had minimum soot concentration of $76.2 \mu\text{gm}^{-3}$ at MU11 location and the maximum of $421.9 \mu\text{gm}^{-3}$ at MU11 location (Fig. 3.30) with a mean value of $421.9 \mu\text{gm}^{-3}$. It varied from $27.8 \mu\text{gm}^{-3}$ at HP5 to $176.4 \mu\text{gm}^{-3}$ at HP7 (Fig. 3.31) with the mean soot concentration of $85.4 \mu\text{gm}^{-3}$. Soot concentration at HU locations ranged from $67.5 \mu\text{gm}^{-3}$ to $391.4 \mu\text{gm}^{-3}$ (Fig. 3.32). The mean soot concentration at HU location was $227.0 \mu\text{gm}^{-3}$. No definite patterns for soot concentrations at the MP, MU, HP and HU locations were observed. At TIF0, TIB0 and TIG0 locations, soot concentrations of $280.0 \mu\text{gm}^{-3}$, $69.4 \mu\text{gm}^{-3}$ and $262.8 \mu\text{gm}^{-3}$ respectively were found (Fig. 3.33 to 3.35). A gradual decrease in soot concentrations at across locations had been observed in both north and south at all three intersections. No soot contents had been found at the farthest locations of TIFN3, TIFS3, TIBN3 and TIBS3 though TIGN3 and TIGS3 had

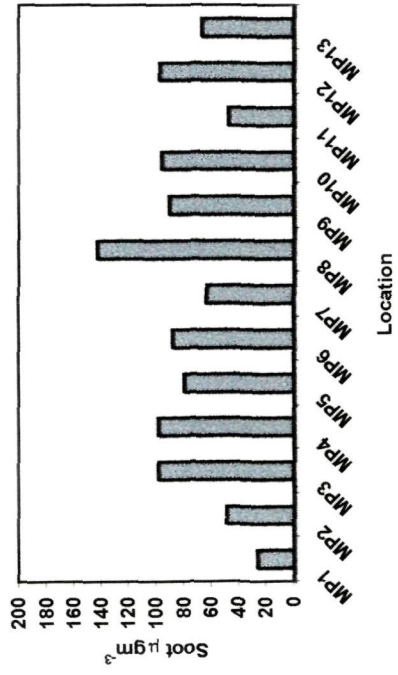


Fig. 3.29 Variations in soot concentrations at MP locations

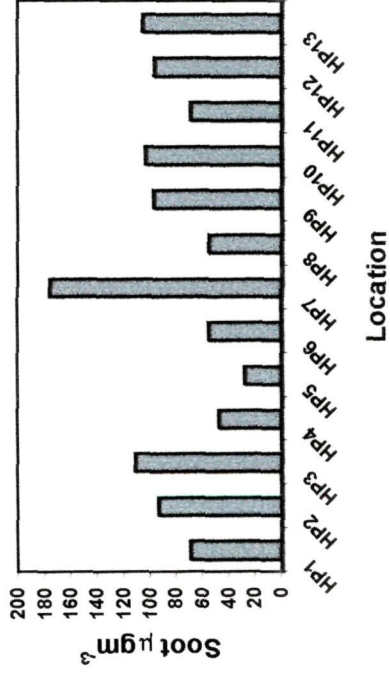


Fig. 3.31 Variations in soot concentrations at HP locations

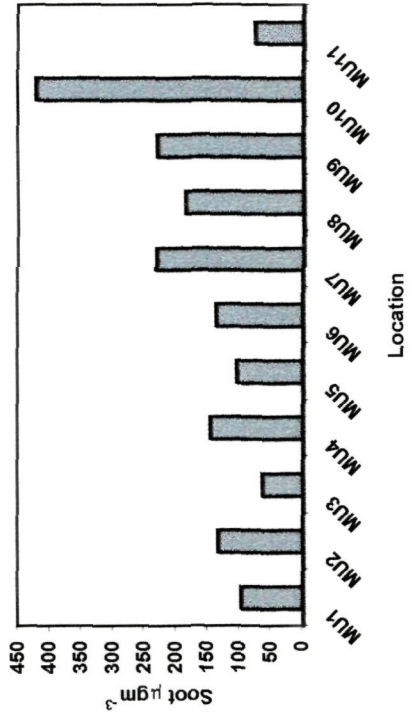


Fig. 3.30 Variations in soot concentrations at MU locations

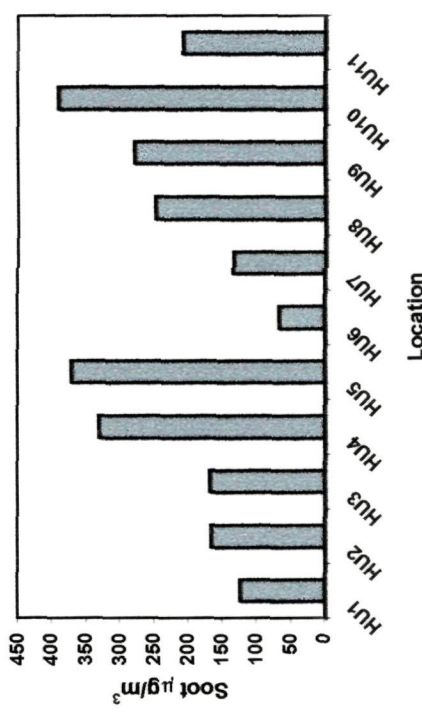


Fig. 3.32 Variations in soot concentrations at HU locations

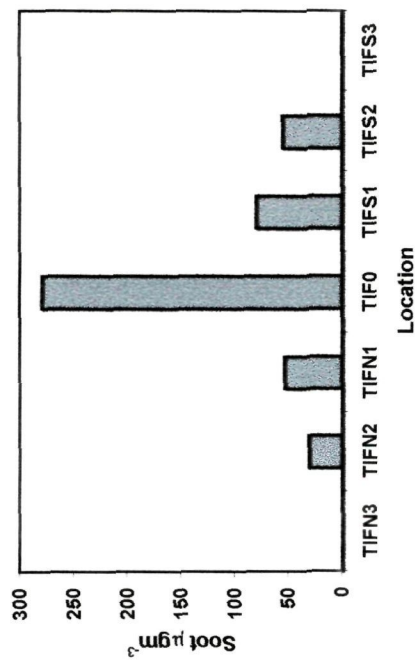


Fig. 3.33 Variations in soot concentrations at TIF locations

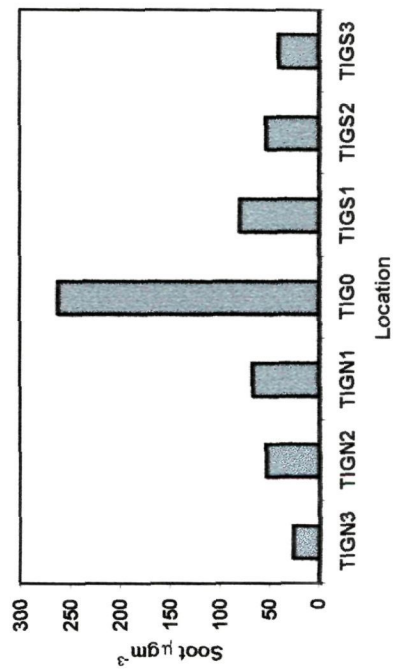


Fig. 3.35 Variations in soot concentrations at TIG locations

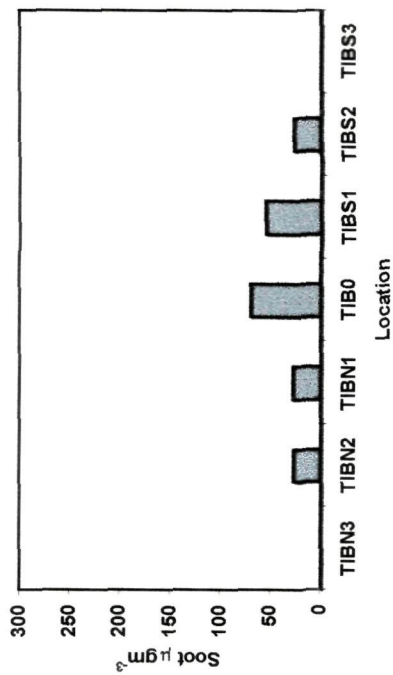


Fig. 3.34 Variations in soot concentrations at TIB locations

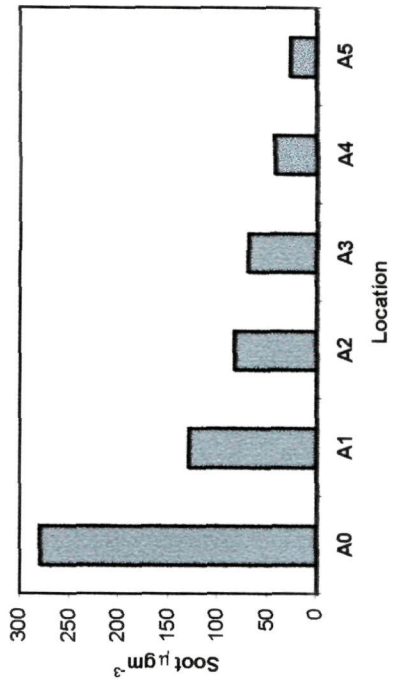


Fig. 3.36 Variations in soot concentrations at A locations



recorded soot concentration of $26.7 \mu\text{gm}^{-3}$ and $40.8 \mu\text{gm}^{-3}$ respectively. The sampling locations across direction at TIG (Garikhana) had been located on higher altitudes with comparatively less green vegetation cover providing the finite probability to observe measurable soot concentrations at these locations. The soot concentration at H1 and H2 was $391.4 \mu\text{gm}^{-3}$ and $152.8 \mu\text{gm}^{-3}$ while at IN1 and IN2 it was $72.2 \mu\text{gm}^{-3}$ and $71.8 \mu\text{gm}^{-3}$ respectively. The mean soot concentrations at H and IN locations were $272.1 \mu\text{gm}^{-3}$ and $72.0 \mu\text{gm}^{-3}$ respectively thus recording a drop of about 74% from outdoor to indoor environment. The IE1 and IE2 had recorded soot concentration of $55.6 \mu\text{gm}^{-3}$ and $225.0 \mu\text{gm}^{-3}$ respectively. The soot concentrations at A locations showed a gradual decrease from A0 location (ground floor), where it was $280.0 \mu\text{gm}^{-3}$ to A5 (rooftop) where it was about $26.8 \mu\text{gm}^{-3}$ (Fig. 3.36).

The concentrations of soot in Shillong were found to be higher in comparison with the major cities of some European countries (Table 3.8) studied

Table 3.8 Comparison of mean soot concentrations of some major cities in Europe with Shillong (μgm^{-3})			
Location	Mean	Maximum	PM/Soot
Amsterdam	15	48	2.92
Berlin	24	65	2.03
Budapest	49	135	1.33
Prague	30	108	1.94
Pisa	20	43	3.20
Athens	109	238	0.88
Oslo	28	104	0.89
Shillong (this study)*	135	422	2.80

* Average of MP, MU, HP and HU locations

under PEACE (Pollution Effects on Asthmatic Children in Europe) study (Hoek *et al.*, 1997). Considerable variability in PM/soot ratios could be observed in European countries (0.88 to 3.2) while in Shillong it was 2.80. The PM/soot ratios for MP, MU, HP and HU locations were 3.6, 2.2, 3.6 and 1.8 respectively which was in accordance with the observations made by Hoek *et al.* (1997). It was also obvious that PM/soot ratio at steep gradient locations became less indicating explicitly that the soot concentration increased at such road conditions.

3.4.7 Relationship of soot with TSP

The least square linear regression lines between soot and TSP for MP, MU, HP and HU locations had also been drawn to establish their interrelationship (Fig.3.37 to 3.40). Soot had positive relationship with TSP at all the category of locations (Eq. 3.17 to 3.20). Soot and TSP relationship had been comparatively strong at high traffic density locations of HP and HU in comparison to low traffic density locations of MP and MU. The correlation coefficients (R^2) for MP, MU, HP and HU locations were 0.57, 0.41, 0.68 and 0.82 respectively. These R^2 values indicated that 57%, 41%, 68% and 82% variance in soot concentrations at MP, MU, HP and HU locations respectively could be explained.

$$\text{Soot (MP)} = 0.1541 * \text{TSP} + 35.042 \quad (3.17)$$

$$\text{Soot (MU)} = 0.6309 * \text{TSP} - 69.06 \quad (3.18)$$

$$\text{Soot (HP)} = 0.2601 * \text{TSP} + 7.109 \quad (3.19)$$

$$\text{Soot (HU)} = 0.4743 * \text{TSP} + 13.243 \quad (3.20)$$

The Pearson correlation coefficients between soot and TSP further

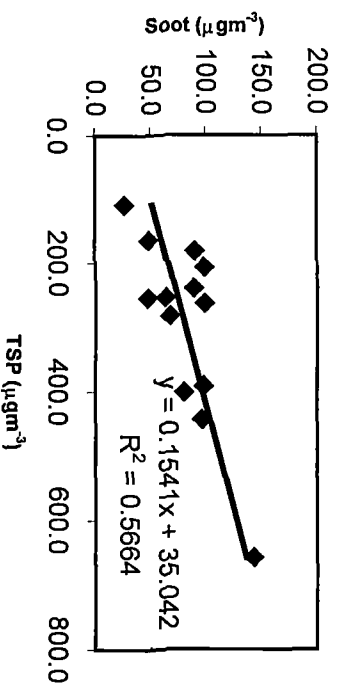


Fig. 3.37 Relationship of soot with TSP at MP locations

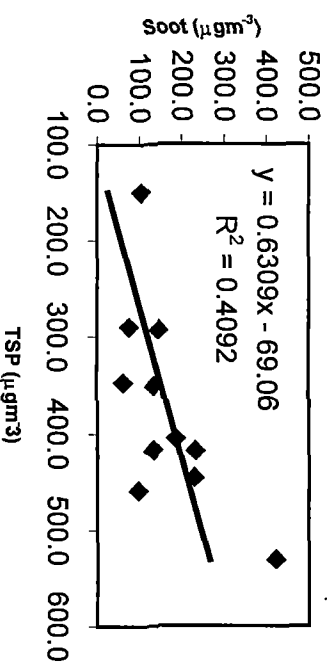


Fig. 3.38 Relationship of soot with TSP at MU locations

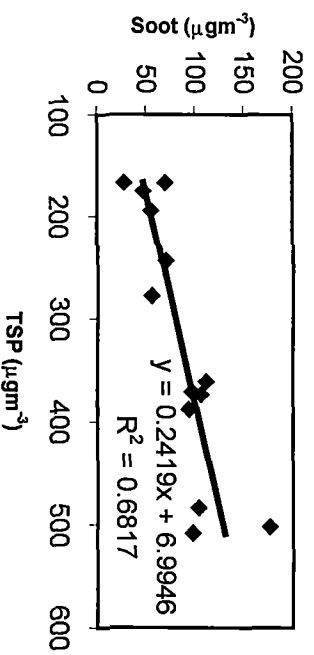


Fig. 3.39 Relationship of soot with TSP at HP locations

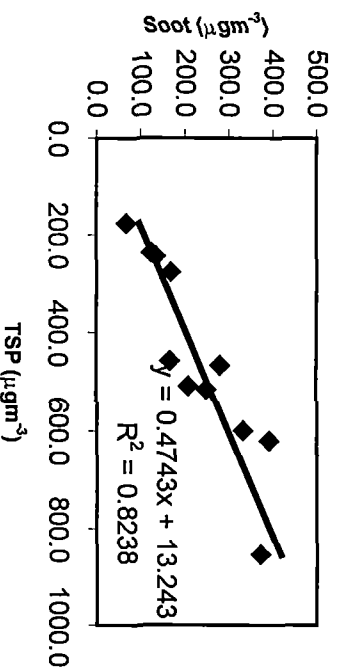


Fig. 3.40 Relationship of soot with TSP at HU locations

established their close relationships (Table 3.9). High and significant correlations were obtained for MP, HP, and HU locations and were also high for MU locations.

Table 3.9 Correlations of soot with TSP	
MP	0.89*
MU	0.55
HP	0.70*
HU	0.90*

* Significant correlation ($P < 0.05$)

3.4.8 Relationship of soot with traffic density

The Pearson correlation coefficients between soot and traffic density are provided in Table 3.10. Soot showed weak correlation with TW at MP location ($r=0.09$) and weak and negative correlation at MU and HU locations ($r=-0.22$ & $r=-0.61$) but had high correlations at HP locations ($r=0.55$). LV showed positive correlations at MP ($r=0.59$, $p < 0.05$) and HP locations ($r=0.32$) and negative correlations at MU ($r=-0.20$) and HU locations ($r=-0.16$). The correlations of soot with HV were high at high-density locations of HP ($r=0.66$, $p < 0.05$) and HU ($r=0.46$). The overall correlations of soot and traffic density (ρ_T) showed positive correlations at MP ($r=0.31$) and HP ($r=0.46$) but negative correlations at MU ($r=-$

Table 3.10 Correlations of soot with traffic density				
Location	TW	LV	HV	ρ_T
MP	0.09	0.59*	-0.31	0.31
MU	-0.22	-0.20	0.17	-0.15
HP	0.51	0.32	0.66*	0.46
HU	-0.16	-0.16	0.46	-0.09

* Significant correlation ($P < 0.05$)

0.15) and HU locations (-0.09). The negative correlations of soot with ρ_T at MU and HU locations was an interesting outcome as it clearly indicated that apart from the vehicle number the other factors such as the steep road gradients and engine conditions also played an equally important role in build up of soot concentrations at *breathing zones in certain areas of Shillong*.

3.4.9 Oil-drops concentrations in TSP

The discussions on oil-drops have been divided into two sub-sections. In the sub-section 3.4.9, we have discussed the OD concentrations (%) in TSP at all the categories of sampling locations. Sub-section 3.4.10 deals with the Pearson correlation coefficients of OD with traffic density and meteorological variables.

The mean OD concentrations for various categories of locations (Tables A.3.19 to A.3.30) indicated that the OD concentrations at CB locations ranged from 12.9% at CB1 to 17.1% at CB2. The cumulative mean OD concentration at CB locations was 15.0% with a peak value of 19.9%. At MP locations, the minimum OD concentration of 3.2% at MP2 and a maximum of 9.8% at MP11 with a peak value of 12.3% at MP6 were observed. The cumulative mean value of OD at MP location was 6.8%. The minimum OD concentration of 3.9% was observed at MU10 location while maximum of 7.3% was found at MU9 location with a peak value of 12.4% at MU3 location. The cumulative mean OD concentration at MU location was 5.9%. At HP locations, the minimum OD concentration of 4.0% was observed at HP9 while the maximum of 10% was at HP7 with the peak value of 16.9% at the same location. The cumulative mean OD concentration at HP locations was 6.3%.

The HP7 location had thick pine forests across the road in the north direction. The minimum OD concentration of 3.0% was found at HU6 location while maximum of 10% was obtained at HU11 with a peak value of 19.6% at HU7. The location of HU7 was also surrounded by thick pine vegetation. The cumulative mean OD concentration at HU locations was 5.7%.

An interesting observation could be made from the above discussion. The presence of OD was small at MP, MU, HP and HU locations and was of the same order, around 6%, of the measured particles at all sampling locations except at the 3 background locations (CB), where it was about 2.5 times more at 15%. This becomes significant, as even the mean TSP concentration at the CB locations was only about $50 \mu\text{g}/\text{m}^3$. Thus OD constituted a large percentage of TSP at CB locations. Certain locations situated on MP, MU, HP and HU also exhibited higher OD concentrations.

The source of these OD was of great interest. The common observation for high OD concentration locations was that pine forests surrounded all these locations and it was not unlikely that the sources of these OD was mostly pine trees.

TIF locations showed a minimum OD concentration of 6.3% at TIFN2 while maximum of 14.7% was observed at TIFS3 location with a peak value of 20.4% at the same location. TIB locations had minimum OD concentration of 3.9% at TIBN1 location and maximum of 11.6% at TIBN3 location with the peak value of 18.5% at the same location. TIG locations showed minimum OD concentration of 3.7% at TIG0 and maximum of 16.2% at TIGS2 location with a peak value of 23.3% at the same location. In case of the various traffic intersection locations, we again observed

the similar trends of high OD concentrations at the locations surrounded by pine trees.

The IN locations exhibited slightly higher cumulative mean OD concentrations of 5.6% in comparison with H locations where it was 3.8%. At IE locations, the OD concentration was quite high at IE1 (14.6%) in comparison with the IE2 (2.1%) with a peak value of 24.8% at IE1. The IE1 location was also surrounded by pine forests and as such showed the similar observance of high OD concentrations.

At A locations, the maximum concentration of 10.4% of OD was observed at A0 while minimum of 3.7% was observed at A4 with the peak value of 13.7% at A0 location. Apart from the higher concentrations at ground level, the other locations at various elevation specific locations showed OD concentrations of about 6% and thus no major trends were observed at these locations.

3.4.10 Relationship of oil-drops with traffic density and meteorological variables

Correlation of OD with traffic density and meteorological variables viz.- ambient temperature, RH, WS and WD at MP, MU, HP and HU locations was examined by computing Pearson correlation coefficients using mean OD concentrations (Tables A.3.20 to A.3.23), mean traffic density (Tables A.1.1 to A.1.4 and A.1.11) and mean meteorological variables (Tables A.2.1 to A.2.9 and A.2.16) to observe the possible contribution of vehicles to OD concentrations in the ambient atmosphere of Shillong (Table 3.11) and relationship of meteorological variables in OD concentration build-up (Table 3.12). The other locations were

excluded because of their diverse nature within a group (traffic intersections and various elevation specific locations) and lack of requisite amount of observations to calculate correlations (H, IN and IE locations).

The correlation between OD and TW was negative and weak at MP, MU, HP and HU locations. The relationship of OD with LV also showed almost similar trends as was observed in case of TW, except that a weak correlation $r=0.25$ at HU. HV showed negative relationships at MP ($r=-0.53$) and HU ($r=-0.06$) and positive correlations at MU ($r=0.33$) and HP ($r=0.13$) locations. The relationship of OD with ρ_T was negative and weak at MP, MU and HP locations ($r=-0.26$, $r=-0.16$ and $r=-0.04$ respectively), while it was positive at HU ($r=0.25$) locations.

Table 3.11 Correlations of oil-drops with traffic density				
Location	TW	LV	HV	ρ_T
MP	-0.08	-0.00	-0.53	-0.26
MU	-0.28	-0.25	0.33	-0.16
HP	-0.04	-0.10	0.13	-0.04
HU	-0.25	0.25	-0.06	0.25

We observed that the OD had rather weak correlations with the traffic density at MP, MU, HP and HU locations, which covered 48 monitoring sites. The OD had positive correlations with ambient temperature at all the locations. At CB locations, the correlation of OD and ambient temperature had been quite strong ($r=0.95$). This was a rather important observation as the role of temperature as a stimulant was already established in the release of terpenes from coniferous vegetation (Tinghey, 1981). The higher concentration of OD around the pine trees and the strong positive correlations with ambient temperature at such locations

undoubtedly signified the role of coniferous plants in elevated concentration of OD near these areas. The correlation of OD with RH was positive at HU locations ($r=0.47$) while it had negative correlations at CB, MP, MU and HP locations ($r=-1.00$, $r=-0.29$, $r=-0.28$ and $r=-0.28$). The strong negative correlations of OD with RH at CB locations signified that at highly humid conditions the rate of the release of OD from vegetation got dropped. The correlations of OD with WS were highly positive at CB locations ($r=0.85$), positive and significant at MP location ($r=0.55$), positive and weak at MU ($r=0.13$) while negative and weak at HP and HU locations ($r=-0.10$ and -0.18). It was noted that cumulative average wind speeds at all categories of sampling locations was high as it was about 10 km/hr. The high positive correlations of OD with WS at CB and MP locations (most of MP locations were surrounded by pine vegetation/forests) implied that high wind speeds facilitated the release and transport of OD at these locations. The correlations of OD with WD were moderately positive at MU and HP ($r=0.42$ and $r=0.31$) while it was highly negative at CB ($r=-0.85$) and negative at MP and HU locations ($r=-0.52$, $r=-0.00$). Wind direction in Shillong changes very frequently and this explained the absence of any specific informative relationships patterns with OD.

Table 3.12 Correlations of oil-drops with meteorological variables				
Location	Amb Temp	RH	WS	WD
CB	0.95	-1.00	0.85	-0.85
MP	0.22	-0.29	0.55*	-0.52
MU	0.10	-0.28	0.13	0.42
HP	0.10	-0.28	-0.10	0.31
HU	0.36	0.47	-0.18	-0.00

* Significant correlation ($P<0.05$)

3.5 CONCLUSIONS

On the basis of the results obtained from characterization of suspended particulates at breathing level of Shillong in terms of sample colors, TSP, soot and OD concentrations and the discussion thereon, the following conclusions have been drawn:

TSP sample colors

- The color of TSP samples provided a fair indication regarding the likely source of soot in particulate matter as it gradually changed from the background gray to the brown and ultimately to the black color at various locations (covering 84 sampling sites) depending upon the intensity of traffic related activities thus establishing that vehicular emissions were the major source of soot at breathing level in ambient air of Shillong.
- Soot particles coagulate fast in highly humid conditions such as in Shillong and settles down. It was evident from the sample colors of the across locations at three traffic intersections.
- Vertical movements of soot particles could be observed up to the monitored height of 17 meters as the sample color changed from the black at breathing level to dark gray at the highest monitored location. This implied that fine soot particles go up to higher levels but the identification of the maximum heights could not be possible due to limitations of the availability of the sampling locations above 17 meters

of height.

TSP concentrations

- The TSP concentrations at the locations not affected by traffic and other intense anthropogenic activities (controls) were found to be low and were well within the prescribed Indian NAAQS.
- The TSP concentrations at breathing level along highways (No 40 & 44) within the city limits, major roads, residential, residential-cum-commercial, commercial, educational and secretarial areas were found to be quite high ranging from “high” to “critical” levels.
- The TSP concentrations showed a gradual decrease at monitored points situated across in north and south of the traffic intersections on highways. The TSP concentrations at the farthest end points at across the locations of traffic intersections were comparable to the TSP levels of CB locations.
- TSP concentrations at IN locations were “moderate” but the drop in concentrations was quite substantial with respect to the H concentrations.
- The TSP concentrations at both IE locations were found to be “critical”.
- Substantial gradual decrease was recorded in TSP levels with increase in heights from ground levels up to 17 meters. This indicated that vertical diffusion of TSP was quite dismal.
- On the basis of the mean TSP concentrations, the Shillong city was

mapped into “low”, “moderate”, “high” and “critical” zones (Fig. 3.41). The map provides a fair indication about areas where the people are exposed to the elevated TSP levels in the city.

- From the least square linear regression plots and calculation of Pearson correlation coefficients we established a fair relationship of TSP concentrations and traffic density at various categories of locations in the city. Also, the diesel operated heavy vehicles were found to contribute higher levels of TSP at steep road gradients as evinced from their strong correlations.
- Meteorological variables showed rather weak interrelationships with TSP. Ambient temperatures showed negative correlations indicating its inverse behaviour with TSP.

Soot concentrations

- No soot concentration was detected at CB locations.
- The soot concentrations were comparatively high at steep gradients road locations of MU and HU perhaps due to high acceleration conditions of vehicles.
- Soot concentrations also showed a gradual decrease at across locations of traffic intersections both in north and south. The farthest end points did not show soot concentrations at two traffic intersections.
- The soot concentrations were quite significant inside houses/shops near the highways, which could pose serious health risks.

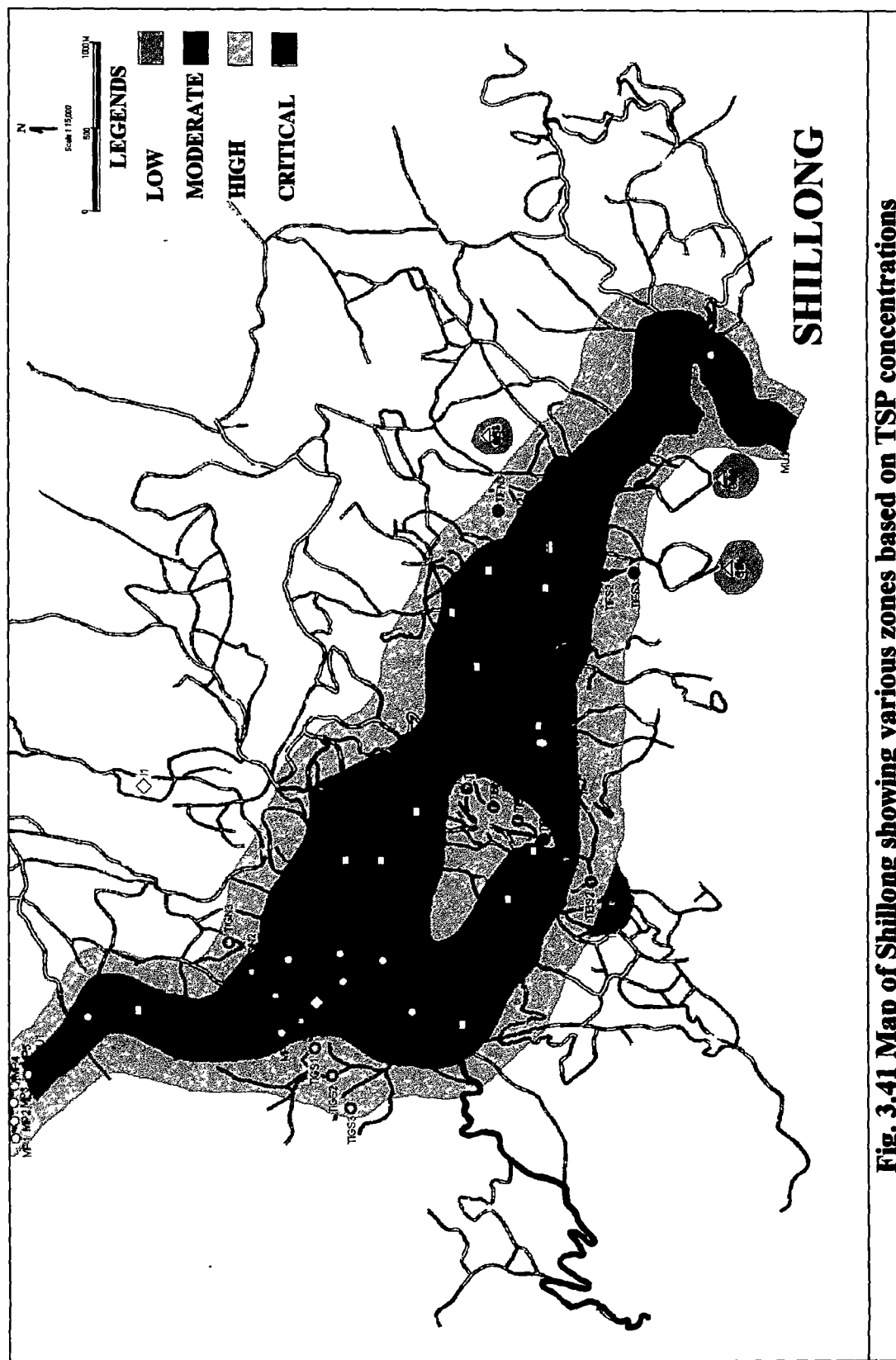


Fig. 3.41 Map of Shillong showing various zones based on TSP concentrations

- Soot concentrations followed a lognormal distribution with respect to TSP. High correlation between soot and TSP was noted at traffic activity areas.
- Comparatively strong correlations between soot and diesel operated heavy vehicle density at steep road gradients indicated higher soot emissions. However, The negative correlations with total traffic density in certain cases implied that factors like engine conditions and road gradient were also equally important.

Oil-drop concentrations in TSP

- High OD concentrations at the locations surrounded by thick pine vegetation were detected. This fact might be attributed to the presence of oils (perhaps terpenes) in pine trees, which were dispersed in the atmosphere due to wind.
- Detection of lower TSP and soot contents in samples of high OD concentrations may be due to its removal by adsorption mechanism.
- Higher ambient temperature and wind speeds increased OD concentrations as evinced from their positive correlations.

CHAPTER 4

CHAPTER 4

DETERMINATION OF AERODYNAMIC SIZE AND DISTRIBUTION PATTERNS OF SUSPENDED PARTICULATES

4.1 INTRODUCTION

A ubiquitous component of air pollution, airborne particulate matter is an intricate mixture of solid and liquid particles with diameters ranging between ~ 0.002 μm and ~ 100 μm . The lower end of the size range is not sharply defined because there is no accepted criterion at which a cluster of molecule becomes a particle. The upper particle size range corresponds to the dimensions of the fine drizzle or very fine sand; these particles are so large that they rapidly fall out of the atmosphere and do not remain suspended for a very significant period of time. The complex size distributions of airborne particulates in ambient systems result from multiple geogenic and biogenic sources generating particles of different sizes, compositions, affinity for liquid water, light scattering and absorption properties and concentration characteristics. Gas-particle conversions are another important secondary source of particulate matter in the atmosphere.

In recent years, the demand for knowledge of various parameters of airborne particulate matter particularly the aerodynamic size has increased with the realization of their potential adverse effects on health and environment. The most important size range of airborne particulates with respect to atmospheric chemistry is $\sim 0.002 \mu\text{m} \sim 10 \mu\text{m}$ (or PM_{10}). The detailed analysis of particle size distribution characteristics, expressed either in terms of mass or number are sometimes more appropriate. In other cases, analyses of more general aspects of distributions add more light to the knowledge of the dynamics of atmospheric process leading to the size distributions. The modality displayed by particle size distributions is one such aspect (Morawska *et al.*, 1999b). The modality or mode in the particle size distributions may be defined as a peak in the size distribution, which can be described by a lognormal function for the number or mass distributions of the atmospheric aerosol (John, 1993). A number of investigations regarding the variation of the airborne particulate size spectrum over a variety of size intervals have been made. Based on the particle numbers, Whitby *et al.* (1975) have illustrated the trimodal nature of atmospheric particulate size distributions that consist of nucleation, accumulation and coarse particle range.

The nucleation range, also termed as “ultrafine particles” (Oberdörster *et al.*, 1995) consists of particles with diameters less than $\sim 0.08 \mu\text{m}$ that are emitted directly from the combustion sources or that condense from cooled gases soon after emission. The lifetime of particles in the nucleation range is less than one hour because they rapidly coagulate with larger particles or serve as nuclei for cloud or fog droplets. This size range is detected only when fresh emission sources

are close to a measurement site or when new particles have been recently formed in the atmosphere (Lundgren *et al.*, 1995).

The “accumulation” range consists of particles with diameters between 0.08 and ~ 2 μm . These particles result from the coagulation of the smaller particles emitted from combustion sources, from condensation of volatile species, from gas to particle conversion and from finely ground dust particles. The nucleation and accumulation range constitute the “fine particle size fraction”, and the majority of sulfuric acid, ammonium bisulfate, ammonium sulfate, ammonium nitrate, organic carbon, soot or elemental carbon is found in this range.

Particles bigger than ~ 2 or 3 μm are generally termed as “coarse particles”. This particle size range mostly results from grinding activities and is dominated by materials of geological origin. Biogenic particles like pollens and spores also inhabit the coarse particles range, as do ground up trash, leaves and tyres. Coarse particles at the low end of the size range also occur when cloud and fog droplets form in a polluted environment, then dry out after having scavenged other particles and gases (Jacob *et al.*, 1986).

In the present work, we have described the inhalation of particulates in section 4.2. This includes the effects of particulates on human health, vegetation, material and buildings and particulate motion, removal mechanism etc. The present approach for particle size distributions forms section 4.3. The experimental aspects are described in section 4.4. This section includes the description of experimental details for determination of particle size distributions for solid particles (PM) and OD using optical microscope and size distributions for some selected locations

with Image Analysis System (IAS) and study of particle morphology by Scanning Electron Microscopy (SEM). Section 4.5 deals with the results and discussion part that contains solid particles size distributions at various categories of sampling locations, linear relationship of PM with traffic density, factor analysis of PM by using Principal Component Analysis (PCA) technique, interrelationship between various sampling locations, relationship with meteorological variables, comparison of optical microscope particle size distribution results with IAS data and morphological analysis of particles with SEM, OD size distributions at various locations and relationship of various OD size groups with traffic density. The conclusions of this part of study are drawn in section 4.6.

4.2 INHALATION OF THE PARTICULATES

Most of the particles having aerodynamic size bigger than 10 μm are removed either in the nasal tract itself or prior to entering deep into the respiratory system. The deposition of the particles in various parts of the human respiratory tract system can be divided into seven broad stages, where particles of different aerodynamic size are lodged. The human respiratory system model and the stages of particulate deposition are shown in Fig. 4.1. The particles that may reach up to Stage 3 and further are quite harmful but the most dangerous ones are those with aerodynamic size of 1 μm or less as these particles are able to penetrate even the alveoli, the deepest part of the lungs.

The particle deposition of various stages basically takes place by the mechanism of inertial impaction, sedimentation and diffusion (Table 4.1). The rapid

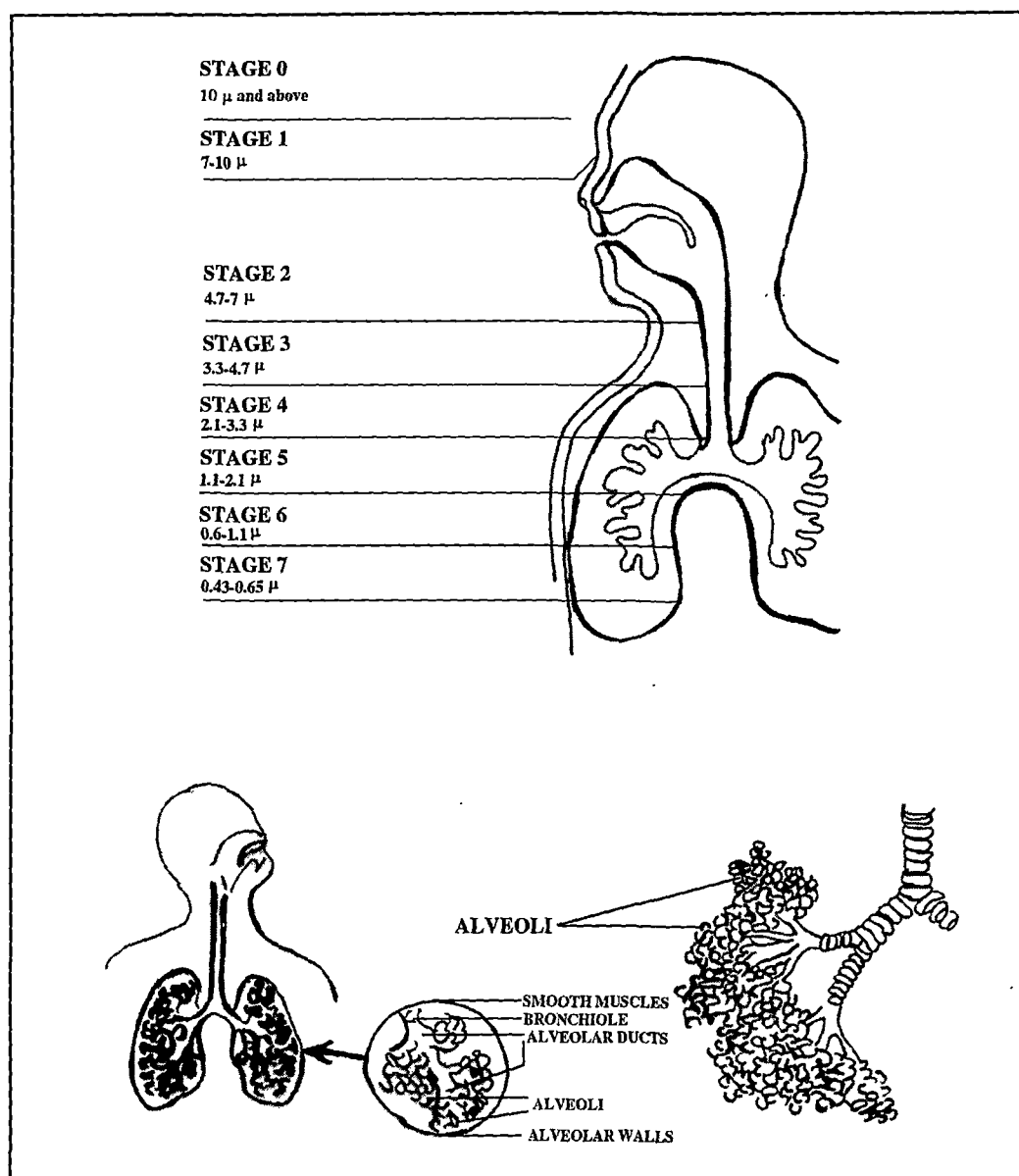


Fig. 4.1 Human respiratory system model and stages of particle deposition

and sharp changes in direction of airflow occurring in the passages of the nose and pharyngeal region favor deposition of larger particles by inertial impaction. In the tracheal bronchiolar region air velocity and directional changes decrease. The smaller particles are distributed throughout the alveolar segments of the respiratory tract. As the velocity decreases to virtually zero, more time is available for

sedimentation to occur, resulting in fewer and fewer particles reaching the alveoli. Gravity becomes less important as the particles become smaller. The particles below 1 μm are deposited on alveolar walls mostly by diffusion. The interaction between particles and cells is largely dependent on where in the respiratory tract the particles will deposit. The particles deposited in the alveoli require more mechanisms for removal than particles that deposit in the upper respiratory tract.

Table 4.1 Mechanisms of particle deposition in respiratory system	
Inertial Impaction	Particles move in straight line. As a change in direction of airflow occurs, particles get deposited. Particle deposition by this mechanism is proportional to particle free falling speed and air velocity
Sedimentation	Deposition is proportional to particle's free falling speed and time available for settling
Diffusion	Significant for fine particles ($< 1\mu\text{m}$) in alveolar region

About 10%-60% of the particles with aerodynamic diameters less than 10 μm (PM_{10}) may deposit in the lung where they may cause harm. The deposition of suspended particulates in lungs is bimodal in nature, peaking at 20% for $\sim 3\mu\text{m}$ particles and at 60% for $\sim 0.03\mu\text{m}$ particles. It was also noted that the amount of particles bigger than 2 or 3 μm transmitted through mouth breathing is significantly larger than the amount transmitted when breathing takes place through the nose. When dry (but soluble) particles enter the human body where the relative humidity exceeds 99%, they grow substantially in diameter. It was also observed that the particle deposition in lungs would increase for soluble particles originally in 0.5 to 1 μm size range as they enlarge by taking on the liquid water. Soluble particles within the droplet mode may cause greater pulmonary aggravation than insoluble particles

that are non-hygroscopic, or soluble particles in the condensation mode.

4.2.1 Effects of particulates on human health

A number of recent time-based epidemiological studies have linked different levels of PM₁₀ with increased incidences and durations of respiratory symptoms, increased hospitalization for respiratory diseases, increased lung dysfunction and increased cardio-pulmonary mortality (Braun *et al.*, 1992; Dockery *et al.*, 1993; Lipfert *et al.*, 1995; Pope, 1992; Schwartz, 1994). These associations have been found across a wide range of coincident weather patterns, and the magnitude of the association is independent of the correlation between particulate air pollution and temperature (Schwartz, 1994). Associations have also been found in locations where co-exposure to sulfur dioxide and ozone were essentially not present. Dockery *et al.* (1994) have reported an increase of 1% in daily mortality with each 10 $\mu\text{g m}^{-3}$ increase in PM₁₀ concentrations. The magnitude of the effect was similar in size with those locations having multiple pollutants exposure. It is now also established that the number of fine particles below 2.5 μm (PM_{2.5}) are most important from the human health perspective as they are able to penetrate deep into the respiratory system and have much longer residence time in the atmosphere compared to the coarser particles (Dockery *et al.*, 1993). Further, because of their relatively larger surface areas, these smaller particles are often associated with a higher proportion of toxic metals and persistence organic compounds as compared to an equivalent mass of coarser particles (Dandson *et al.*, 1974). PM_{2.5} readily infiltrate inside the residential buildings making the indoor levels similar to levels immediately outside

the structure (Brauer *et al.*, 1989). Schwartz *et al.* (1996) has observed that an increase in PM_{2.5} across its range of exposure (5th to 95th percentile) was associated with a 5.8% increase in daily deaths. Epidemiological evidence also suggests that there may be no safe threshold limits for fine particulates and that the effects are linearly related to concentration (Schwartz, 1991/92; Schwartz *et al.*, 1992).

4.2.2 Effects of particulates on vegetation

Vegetation exposed to wet and dry deposition of particulates may be injured when particulates are combined with other pollutants. Coarse particles, such as dust, directly deposited on leaf surfaces can reduce gas exchange and photosynthesis capabilities, leading to stunted plant growth. Particulate soot that fall from atmosphere on vegetation causes considerable damage to plant life (Brimblecombe, 1986). Heavy metals that may be present in particulates, when deposited on soil, inhibit soil process that makes nutrients available to plants. This, combined with effects of particulates on leaves may contribute to the reduction in plant growth and yields. Particulate emissions have their greatest impact on terrestrial ecosystem in the vicinity of emission sources. Ecological alterations may be the results of high particulate concentrations (World Bank Group, 1988).

4.2.3 Effects of particulates on materials, buildings and others

Soiling of the external surfaces of buildings and architecture is associated mainly with the deposition of aerosol particulates (Butlin, 1991; Del Monte *et al.*, 1984; Hoffman, 1984), the rate of which is dependent on factors such as particulate concentrations, particulate color, the roughness of deposition surface, orientation of

the surface (vertical, horizontal etc.), efficiency of resuspension mechanism by wind and washing out by wind and rain (Pio *et al.*, 1998). Smoke particles, produced by the incomplete combustion of carbonaceous fuels, are the main cause of the surface soiling in the long run, principally in the urban atmosphere (Mansfield *et al.*, 1991). The problem is more intense in the developing countries where the levels of soot in urban atmosphere are supposed to be quite high (De Koning *et al.*, 1986; Joumard, 1993; Smith *et al.*, 1996; Yousufzai, 1991). The transformation of limestone to gypsum and attack on medieval window glasses are other serious problems caused by particulates. Fine particulates have also been found associated with aesthetic problems such as visibility degradation with haze.

4.2.4 Atmospheric particle motions and removal mechanisms

To understand the particulate removal mechanism from the atmosphere, it is necessary to know the particulate motion characteristics of various size groups, which is determined by the kinetic properties of gas and other external forces that act on the particles. The following phenomena can produce forces that result in motion, transport or deposition of particles: gravitational and electrical fields, drag forces, centrifugal flows, inertial forces, shear gradients, Coriolis forces and concentration and thermal gradients. Interfacial phenomenon includes evaporation, condensation, nucleation, adhesion and electrical charging of the particles. Evaporation and condensation of droplets change the size distributions of the particles. Evaporation reduces or eliminates some particles; condensation leads to the growth of other particles. Critical diameter that depends on vapor pressure is

used to determine which particles will grow by condensation. Particles smaller than the critical diameter will evaporate with their mass becoming available to aid in the growth of larger particles. Adhesion forces arise from particle and surface properties, interface geometry and gas constituents. When small particles deposit on a solid surface, they usually adhere on contact due to these forces. The adhesive forces can be increased by particle electrostatic charge but high humidity counteracts this effect. The electrostatic charge associated with suspended particulates consists of an excess or deficiency of electrons or an excess of ions attached to particle. Most small particles have naturally acquired charges from electron transfer during contact or separation or because of free-ion diffusion. Collision and adhesion of oppositely charged particles affect sedimentation rates. The maximum likely particle charge increases with particle diameter.

External forces that may act on aerosol particles include gravitational, electrical, thermal and molecular forces. Sedimentation resulting from gravity leads to particles settling out of a stream on horizontal surfaces (Owen *et al.*, 1992). The settling velocity of a spherical particle can be closely approximated by Stokes' law and is directly proportional to the square of particle diameter:

$$v = D^2 \rho g / 18\eta \quad (4.1)$$

(where v is the particle velocity relative to gas, D is the particle diameter, ρ is the particle density, g is gravitational force and η is gas viscosity)

The settling velocity thus increases with the density of the particle and with the square of its diameter. The expression given for the terminal settling velocity

(when a force such as gravity is applied to the particle, it speeds up until the frictional force equals the applied force; it then moves with a constant velocity known as terminal velocity) applies to the particles with diameters $\geq 1.5 \mu\text{m}$.

However, as the particles become smaller, the air molecules appear less as a continuous fluid and more as discrete molecules separated by space through which the particles can “slip”. The net effect is that particles can move faster due to this slipping between gas molecules. The settling velocity for small particles ($0.1 \mu\text{m} \leq 1.5 \mu\text{m}$) can be given as:

$$v = D^2 \rho g C / 18 \eta \quad (4.2)$$

where C is the correction factor known as Cunningham correction factor which is represented by:

$$C = 1 + 2.514 \tau / D \quad (4.3)$$

(where τ is the mean free path between air molecule collisions defined as the average distance traveled between collisions with another molecule)

The settling velocity of particles with diameter of $\geq 10 \mu\text{m}$ (with $\rho = 1 \text{ gm cm}^{-3}$ in still air at 0°C and 1 atmospheric pressure) will be $\geq 0.1 \text{ cm S}^{-1}$ and hence will settle out of atmosphere relatively rapidly. However the particles with diameter $\geq 1 \mu\text{m}$ will remain suspended for long periods of time (Barbara *et al.*, 1986). Impaction occurs when a particle collides with an obstacle in the flow path. Smaller particles follow the gas flow lines around an obstacle, whereas larger particles, owing to their inertia, are unable to change their direction. Thus

impaction shifts the particle size distribution towards the smaller particles. Diffusion of aerosol particles in a gas, a micro scale mechanism, is the result of their bombardment by molecules (Brownian motion). Diffusion is seldom considered for particles bigger than 1 μm in diameter. In fact, in the absence of convection, ultra fine and fine particles are transported primarily by diffusion; this is primarily responsible for rapid coagulation of particles in the nucleation range. Particles always tend to diffuse from a region of higher concentration to one of lower concentrations. The particle diffusion can be represented by Fick's first law of diffusion:

$$J = - D \cdot dN/dx \quad (4.4)$$

(where J is the flux of particles crossing a 1 cm^2 plane in 1 s, D is the diffusion coefficient and dN/dx concentration gradient. The rates of diffusion (D) increase with temperature and decrease with increasing gas viscosity and particle size)

The calculated rates of settling and diffusion are applicable to still air. In fact, the air in the atmosphere is rarely still and is usually undergoing some degree of turbulent motion making the transport of particles more complex and faster due to velocity gradients and contorted patterns of airflow.

Apart from settling, diffusion and coagulation, scavenging of particles due to their capture by precipitation size water drops (Byrne, 1993) and rain are other important processes of particulate removal from the atmosphere.

4.3 THE PRESENT APPROACH FOR DETERMINATION OF PARTICLE SIZE DISTRIBUTIONS

Unlike other air pollutants, which are characterized by total concentrations,

airborne particulate matter can be characterized by a range of different parameters including total mass or number concentrations, mass or number size distributions, modality of size distributions, count median diameter of the distributions or of the modes in distributions. Current air quality standards are expressed in terms of particle mass concentration as PM_{10} and $PM_{2.5}$, which are mass concentrations of particles with diameters smaller than 10 or 2.5 μm (In India, mass based NAAQS for PM_{10} only has been notified). One major limitation of using mass standards is that the values are heavily biased towards larger particles; the mass of a small number of large particles can be significantly larger than the mass of a large number of small particles (Morawska *et al.*, 1999a). In ambient environment, concentrations of small particles are usually significantly higher than the concentrations of larger particles, and it thus appears that for health risk assessments, knowledge of particle number concentration could be more important than knowledge of particle mass (Li *et al.*, 1996; Oberdörster *et al.*, 1994; Seaton *et al.*, 1995). New research efforts are also directed towards experimental characterization of particle number distributions. However, the particle number concentration needs to be related to the mass concentrations as the current standards are mass based. There are various uncertainties in relating particle number concentration with particle mass concentrations. The main problems are i) need to make assumptions about particle density ii) variations in density of ambient aerosols with time iii) differences in size ranges in which any pair of mass and number measuring instruments used for experimental comparison operate, and iv) the need to make assumptions about the spherical shape of the particles. While the laboratory scale experiment conducted

with known constitution of aerosol particles provide reasonable particle number and mass relationship but the same was not true in case of the field observations of ambient aerosols, which is due to the fact that most ambient particles are complex mixtures from different sources, and the contribution of these sources change at different times of the day and depends on local patterns of generation (Morawska *et al.*, 1999a).

Owing to the uncertainties in the above methodologies and in view of the fact that mass based particulate distributions may not explain the health risks in clear terms, we have adopted slightly different approach for determination of particle size distributions. As already mentioned, we used optical microscope for determination of particle size number distributions and presented the results in percent (%) relative abundance in terms of number percentage for various size groups as described in the subsequent sections to make the particulate size distributions more realistic for assessment of health risks. Some other workers have also used light microscopy to obtain more specific information regarding the particle shapes and sizes (Crutcher, 1982; Fletcher *et al.*, 1993; McCrone *et al.*, 1973).

4.4 EXPERIMENTAL ASPECTS

The experimental aspects covering details about the preparation of microscopic slides, determination of particle size distributions with optical microscope, determination of particle size distributions with IAS and determination of particulate morphology with SEM are provided in the following sub-sections.

4.4.1 Preparation of microscopic slides

For better reproducibility of the particle size distribution results, we used a different technique. Under this method, instead of putting the sampled particulates directly on the microscopic slides, we thoroughly cleaned the slides and glass-covers with chromic acid and acetone and dried them in a hot air oven for 1 h at 40°C. The pieces of Mylar (chemical composition: $C_{10}H_8O_4$, density: 1.49 g/cm³, thickness: 25 µm) were cut in 1cm x1cm size and cleaned with tissue papers. The cleaned Mylar sheets were pressed with slight but uniform pressure against the filter paper containing aerosol samples collected as described in Chapter 3, section 3.3.4. A uniform thin layer of the particulates was deposited on the Mylar sheet. The Mylar sheet containing particulate matter was then placed on an already clean microscope slide and was covered with a glass slide cover fixing the edges with a clear lacquer effectively. The prepared slides were kept in the environment free from dust and other contaminants for determination of particle size.

4.4.2 Determination of particle size by optical microscope

The measurement of particle size was carried out using an optical microscope (Laborlux D, Leitz, Wetzlar, Germany) at a magnification of 1562X. The microscope was calibrated prior to particles size measurements using a standard stage micrometer scale to find the calibration factor. The exact number of divisions in the stage micrometer scale coinciding with the number of divisions in the eyepiece scale gave calibration of one division of the eyepiece scale. Using this scale the area of detector surface magnified at a particular magnification was

calculated. In Leitz microscope an objective of 100X (water immersion) magnification was used. The eyepiece was fitted with a square grid (1cm x 1cm divided into 100x100 grids). The smallest division on the eyepiece micrometer at this magnification corresponds to 0.8752 μm . The details of calibration factor are shown in Table 4.2:

Table 4.2 Calibration of Leitz microscope	
Objective Magnification	F (μm)
10X	9.0140
25X	3.5555
40X	2.2400
50X	1.8000
100X	0.8752

One of the two eyepieces of the microscope had a linear scale disc with 100 divisions and the other one a grid disc of 100X100 divisions thus covering an area of 7656.25 μm^2 of the slide. One half of a division could be observed with a fair accuracy with insignificant uncertainties in the observed lengths therefore measuring the minimum particle aerodynamic size of 0.44 μm . To measure the particle size, first the total sample area on the slide was scanned for any peculiar shape and size of particulate deposition. Then an area under the grid was randomly selected and the particles observed within the area were measured with the help of a micrometer having a linear scale. For each particle 'Feret's diameter' (Fig. 4.2), the gauge of distance between two tangents at opposite end of the particle, was measured (Barbara *et al.*, 1986; PCEH, 1988a). The PM in the range of 0.44 μm to $\geq 10.5 \mu\text{m}$ and the OD from 0.44 μm to $\geq 5.3 \mu\text{m}$ were measured and recorded. About 1000

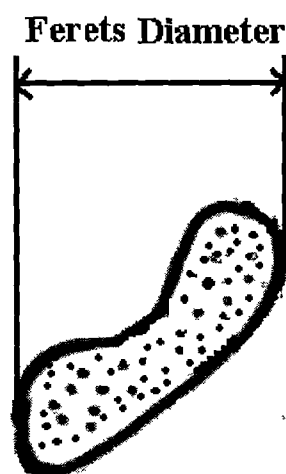


Fig. 4.2 Feret's diameter of particle

particles were measured for every sample. The particle size results were pooled in two broad size groups viz.-fine particle size group of $PM_{2.5}$ that contain particulates of $PM_{0.44}$ ($0.44\ \mu m$), $PM_{0.88}$ ($0.88\ \mu m$), $PM_{1.77}$ ($1.77\ \mu m$), and $PM_{2.6}$ ($2.6\ \mu m$), and another size group that contains particle spectrum of cumulative $PM_{2.5}$ ($0.44\ \mu m$ - $2.6\ \mu m$), PM_5 ($3.5\ \mu m$ - $5.3\ \mu m$), PM_{10} ($6.1\ \mu m$ - $10.5\ \mu m$), and coarse PM ($>10.5\ \mu m$) for solid particles. The fine particulate size group was to provide the distributions of particles within this size range ($PM_{2.5}$) while the group with cumulative $PM_{2.5}$, PM_5 , PM_{10} and $PM_{>10}$ was for better understanding of the size distributions of atmospheric particulates in Shillong. Though, averaging overall particles in a given size range leads to certain loss of information on the particles but the type of data obtained are quite useful in discussion of results and estimating health risks (Friedlander, 1973). Accordingly, the size of OD was also determined and grouped in size ranges of fine oil-drops of $OD_{2.5}$ containing $OD_{0.44}$ ($0.44\ \mu m$), $OD_{0.88}$ ($0.88\ \mu m$), $OD_{1.77}$ ($1.77\ \mu m$) and $OD_{2.6}$ ($2.6\ \mu m$) and another size group of

cumulative OD_{2.5} (0.44 μ m - 2.6 μ m), OD₅ (3.5 μ m - 5.3 μ m) and OD_{>5} (>5.3 μ m).

4.4.3 Determination of particle size by image analysis system

Image Analysis System (Leica DMR, Germany) was used at a magnification of 1000X for determination of particle size distributions for some selected samples. The system was based around the Microsoft windows operating environment providing an easy interface to access the extensive image processing and measurement facilities. The same microscope slides used for determination of particle size with optical microscope as described in section 4.4.1 were used for IAS as well. The IAS covered an area of 76360 μ m² of the slide for one measurement. To measure the particle size, first the total sample area was scanned for any peculiar size and shape of particulate deposition. Then an area of the slide was randomly selected. For each particle 'Feret's diameter' was obtained. The PM in the range of 0.44 μ m to $\geq$ 10.2 μ m were measured and recorded. At least 2-3 areas of the slide were randomly selected and a few thousand particles were measured for each sample. For a clear view in data presentation, the measured particle size results were also aggregated in two similar size groups viz. fine particle size group of PM_{2.5} containing particles of PM_{0.44} (0.44 μ m), PM_{0.88} (0.88 μ m), PM_{1.77} (1.77 μ m), and PM_{2.6} (2.6 μ m), and inhalable and coarse size groups of cumulative PM_{2.5} (0.44 μ m - 2.6 μ m), PM₅ (3.5 μ m - 5.3 μ m), PM₁₀ (6.1 μ m - 10.2 μ m), and coarse PM (>10.2 μ m). The digital micro images of particle size distributions for various categories of sampling locations were also obtained.

4.4.4 Determination of particulate morphology by scanning electron microscope

For determination of the morphology of the airborne particles, a small piece of sample was cut from the membrane filter containing particulate sample. First, sample preparation was performed by doing gold plating for all the samples using Ion Sputter JFC-1100. The gold coating was applied for 15 minutes under vacuum at 10 mA and 1kV conditions. After the completion of the coating for 15 minutes, the system was allowed to cool and the samples were taken out from the chamber. The approximate thickness of gold coating on the samples was 150 nm. The gold plating was done to make the filter surface conducting. A JSM-35 CF Scanning Electron Microscope was used for conducting scanning electron microscopy of these uniformly gold-coated samples under complete vacuum conditions. The morphology of the airborne particles at various categories of locations was studied by the obtained photomicrographs of the analyzed samples.

4.5 RESULTS AND DISCUSSION

We have divided the discussion part into 10 sub-sections. In sub-section 4.5.1, we have discussed the average particles size distribution values (% relative abundance) for fine particulate group ($PM_{2.5}$) and cumulative $PM_{2.5}$, PM_5 , PM_{10} and $PM_{>10}$ size groups obtained with optical microscope at all categories of sampling locations and compared our results with that of the other cities. The temporal variations in particles size distributions for various particulate are discussed in sub-section 4.5.2. The linear relationship of various particles size groups with traffic density at MP, MU, HP and HU locations constitute sub-section 4.5.3. This sub-

section also includes the Pearson correlation coefficients for particles size groups with traffic density. To obtain the number and nature of polluting sources of suspended particles, the concentration (% relative abundance) of fine particle size group ($PM_{2.5}$) and cumulative $PM_{2.5}$, PM_5 , PM_{10} and $PM_{>10}$ size groups were subjected to factor analysis using Principal Component Analysis with Varimax Rotation method (Varimax rotation maximizes the variances of normalized factor loading across variables for each factor), a technique for modeling a set of data onto itself and the results obtained in the form of new latent variables called Principal Components (PCs) or factors are discussed in sub-section 4.5.4. This technique has been widely applied to the source apportionment of air pollutants measured at a receptor point (Harrison *et al.*, 1996; Harrison *et al.*, 1997; Sharma *et al.*, 1992; Thurston *et al.*, 1985; Väkevä *et al.*, 1999). The sub-section 4.5.5 deals with the Pearson correlation coefficients of fine particle size group ($PM_{2.5}$) and cumulative $PM_{2.5}$, PM_5 , PM_{10} and $PM_{>10}$ with meteorological variables. All statistical analysis was performed with the help of the software “STATISTICA” Release 4.5 of StatSoft, Inc., 1993. The particle size distributions for some select sampling locations determined by IAS are provided in sub-section 4.5.6. This sub-section also includes the comparison of particle size distribution results obtained by IAS with that determined with optical microscope for verification and authentication of microscopic particle size distribution data together with digital images of some locations. The morphology of suspended particles analyzed with SEM is described in sub-section 4.5.7.

In sub-section 4.5.8, we have discussed the average values of OD

distributions (% relative abundance) for OD of various size groups obtained with optical microscope. The temporal variations in OD distributions have been discussed in sub-section 4.5.9. The relationship of various size groups of OD with traffic density is described in sub-section 4.5.10.

4.5.1 Solid particle size distributions

The average values for size distributions of fine particles spectra ($PM_{2.5}$) are given in Table 4.3. The relative abundance of $PM_{0.44}$ at CB location was 16.3% with a peak value of 21.1%. The concentration of $PM_{0.44}$ had increased at MU, HP and HU locations (excluding MP locations where it was inexplicably 15.6%, but with peak value of 26.2%) where it had been 20.5%, 21.8% and 23.9% with the peak value of 30.1% at MU locations, thus recording a maximum increase of 7.6% at HU locations in comparison to CB locations. The relative abundance of $PM_{0.44}$ at traffic intersection locations of TIF0, TIB0 and TIG0 was 30.7%, 24.6% and 32.5% respectively with the peak value of 43.5% at TIG0, thus an increase of 16.2% had been observed in comparison with $PM_{0.44}$ concentration at CB locations. The $PM_{0.44}$ concentrations at H and IN locations were 26.5% and 18.3% respectively with a peak value of 27.8% at H locations. $PM_{0.44}$ concentration at IE locations was 21.0% while at A0 it was 19.9%. It was obvious that $PM_{0.44}$ concentration increased with increase in traffic activities.

The relative abundance of $PM_{0.88}$ at CB locations was 17.2% with the peak value of 20.6%. The relative abundance of $PM_{0.88}$ at MP, MU, HP and HU locations was 22.4%, 23.7%, 23.5% and 24.5% respectively with the peak value of 34.3% at

Table 4.3 Distribution of fine particulates (PM_{2.5}) at various categories of locations in Shillong (% relative abundance) - this study

S No	Location	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size
		Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
1	CB	16.3 ± 6.5	21.1	17.2 ± 3.0	20.6	16.5 ± 2.3	18.2	9.1 ± 2.0	11.4	6
2	MP	15.6 ± 5.5	26.2	22.4 ± 6.3	34.3	18.8 ± 2.4	23.0	9.1 ± 2.5	15.9	31
3	MU	20.5 ± 4.9	30.1	23.7 ± 5.4	32.5	16.4 ± 2.2	20.8	9.1 ± 1.4	11.6	27
4	HP	21.8 ± 3.6	29.3	23.5 ± 1.6	25.9	20.0 ± 2.8	25.2	8.7 ± 1.0	10.2	35
5	HU	23.9 ± 4.0	29.0	24.5 ± 2.1	29.2	18.6 ± 2.0	22.1	8.8 ± 2.0	12.7	26
6	TIF0	30.7 ± 14.0	40.6	26.0 ± 1.8	27.3	15.0 ± 2.1	16.4	7.6 ± 2.7	9.5	2
7	TIB0	24.6 ± 14.9	35.1	17.8 ± 3.5	20.3	19.3 ± 3.8	22.0	12.7 ± 2.3	14.3	2
8	TIG0	32.5 ± 15.6	43.5	30.7 ± 4.0	33.5	14.5 ± 4.3	17.5	9.3 ± 5.2	12.9	2
9	H	26.5 ± 1.8	27.8	28.1 ± 4.2	31.1	18.2 ± 1.1	19.0	8.0 ± 0.2	8.2	4
10	IN	18.3 ± 2.6	20.1	21.3 ± 3.9	24.1	16.0 ± 1.2	16.9	7.4 ± 0.4	7.7	4
11	IE	21.0 ± 12.7	30.0	22.3 ± 4.6	25.6	19.9 ± 1.9	21.3	8.1 ± 3.6	10.7	4
12	A0	19.9 ± 1.3	20.8	25.3 ± 0.9	25.9	17.6 ± 1.7	18.8	9.5 ± 0.1	9.5	2

MP location, thereby, recording a maximum increase of 8.2% for PM_{0.88} at HU locations in comparison to the CB locations. The relative abundance of PM_{0.88} at TIF0, TIB0 and TIG0 was 26.0%, 17.8% and 30.7% respectively with the peak value of 33.5% at TIG0. PM_{0.88} concentrations at H and IN locations were 28.1% and 21.3% respectively with a peak value of 31.1% at H locations. The concentration of PM_{0.88} at IE locations was 22.3% while at A0 it had been 25.3%. PM_{0.88} also showed

increasing trends at traffic activity related locations.

The relative abundance of $PM_{1.77}$ at CB location was 16.5% with the peak value of 18.2% and at MP, MU, HP and HU locations, it was 18.8%, 16.4%, 20.0% and 18.6% respectively with a peak value of 25.2% at HP locations. A distinct pattern was evident from these observations as the concentration of $PM_{1.77}$ was more at MP and HP locations in comparison to MU and HU locations. The concentration of $PM_{1.77}$ at TIF0, TIB0 and TIG0 was 15.0%, 19.3% and 14.5% respectively with a peak value of 22.0% at TIB0. The concentration of $PM_{1.77}$ at H and IN locations was 18.2% and 16.0% respectively with a peak value of 19.0% at H location. $PM_{1.77}$ concentration at IE locations was 19.9% while it had been 17.6% at A0.

The relative abundance of $PM_{2.6}$ did not show much variation in concentrations. It was about 9.0% at CB locations but varied from 7.6% at TIF0 to 12.7% at TIB0. Thus, we observed a definite increase in concentration of $PM_{0.44}$, $PM_{0.88}$ and $PM_{1.77}$ at locations with traffic activities while change in concentration of $PM_{2.6}$ did not demonstrate much variation in comparison with the CB locations.

The average values for cumulative $PM_{2.5}$, PM_5 , PM_{10} and $PM_{>10}$ are given in Table 4.4. The relative abundance of cumulative $PM_{2.5}$ at CB locations was 59.1% with the peak value of 59.6%. The concentration of cumulative $PM_{2.5}$ at MP, MU, HP and HU locations was 65.3%, 69.5%, 74.0% and 79.0% respectively with the peak value of 84.3% at MP location. Thus, the maximum increase of 19.4% in cumulative $PM_{2.5}$ concentrations had been recorded in case of HU locations in comparison with the CB locations. The concentration of cumulative $PM_{2.5}$ at TIF0, TIB0 and TIG0 was 79.0%, 74.4% and 86.9% respectively with a peak value of

94.0% at TIG0. The concentration of cumulative $PM_{2.5}$ at H and IN locations was 80.9% and 63.0% respectively with a peak value of 85.8% at H locations. The concentration of cumulative $PM_{2.5}$ at IE location was 71.2% and at A0 it had been 72.3%. An explicit increasing trend in concentration of cumulative $PM_{2.5}$ had been elicited at the locations having traffic movements.

Contrary to the observations made with respect to cumulative $PM_{2.5}$ concentrations, the relative abundance of PM_5 was highest at CB locations, where a concentration of 19.8% had been recorded with a peak value of 22.0%. The minimum PM_5 concentration of 6.6% was obtained at TIG0, which had the distinction of the highest cumulative $PM_{2.5}$ concentration as well.

PM_{10} showed similar trends as observed in case of PM_5 concentrations. The relative abundance of PM_{10} was 13.7% at CB locations with a peak value of 14.6%. The highest PM_{10} concentration at any traffic activity related location had been of 11.6% recorded at MP locations while the lowest concentration of 3.9% was recorded at TIG0. At IN locations, the concentration of PM_{10} was 12.3%.

The variations in $PM_{>10}$ concentrations at CB locations and traffic activity related locations were not very significant as $PM_{>10}$ at CB locations was 7.5%, while at traffic related locations it ranged from 2.6% at TIG0 to 8.2% at MP locations. The highest concentration of $PM_{>10}$ had been obtained at IN location where it was 11.4%.

From the observations above, we noticed that about 75% of the particles at traffic activity related locations (excluding CB and IN) belonged to $PM_{2.5}$ while 94.0% had been found to be within the respirable range of PM_{10} in Shillong. Such

Table 4.4 Particle size distributions in Shillong (% relative abundance) — this study										
S No	Location	Cum. PM _{2.5}		PM ₅		PM ₁₀		PM _{>10}		Sample Size
		Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
1	CB	59.1 ±0.5	59.6	19.8 ±2.4	22.0	13.7 ±1.4	14.6	7.5 ±1.9	9.5	6
2	MP	65.3 ±12.3	84.3	15.0 ±3.9	22.2	11.6 ±5.2	21.9	8.2 ±4.6	16.9	31
3	MU	69.5 ±8.3	80.4	14.3 ±2.9	18.7	9.8 ±3.7	17.2	6.4 ±2.9	13.4	27
4	HP	74.0 ±4.4	79.1	12.5 ±2.9	18.0	8.2 ±2.9	12.9	5.4 ±2.0	7.8	35
5	HU	75.8 ±3.0	81.5	11.6 ±1.5	14.3	8.1 ±1.1	10.3	4.4 ±1.4	7.1	26
6	TIF0	79.0 ±11.1	87.1	9.7 ±6.7	14.4	5.0 ±1.9	6.3	6.1 ±2.7	8.0	2
7	TIB0	74.4 ±12.3	83.1	9.9 ±3.6	12.4	9.6 ±4.8	13.0	6.2 ±3.9	8.9	2
8	TIG0	86.9 ±10.1	94.0	6.6 ±3.8	9.3	3.9 ±3.8	6.6	2.6 ±2.3	4.2	2
9	H	80.9 ±6.9	85.8	8.7 ±3.6	11.3	6.4 ±1.5	7.5	4.8 ±1.6	6.0	4
10	IN	63.0 ±8.0	68.7	13.3 ±2.3	14.9	12.3 ±2.8	14.3	11.4 ±3.0	13.6	4
11	IE	71.2 ±11.8	79.6	13.2 ±5.6	17.1	9.8 ±1.6	10.9	5.9 ±4.7	9.2	4
12	A0	72.3 ±1.2	73.1	13.4 ±1.5	14.4	7.3 ±1.3	8.2	7.2 ±1.2	8.0	2

high percentage of PM_{2.5} and PM₁₀ exposes the population residing along highways/major roads to serious health risks.

Although, several workers had studied the particle size distribution patterns in atmosphere in various urban centres (Table 4.5) but these were mostly based on particulate mass concentrations. In recent times, the need for number based particle size distributions has been found to be important but there is an unambiguous dearth of particle size distribution trends based on the number concentrations or percent

Table 4.5 Size distribution of particulates at various cities in the world

S No	Location	PM _{2.5} %	PM ₁₀ %	PM _{>10} %	Reference
1	Geneva	80.8	13.6	5.4	Monn <i>et al.</i> , 1999
2	Lugano	79.1	17.1	3.8	Monn <i>et al.</i> , 1999
3	Aarau	83.8	13.2	3.0	Monn <i>et al.</i> , 1999
4	Wald	84.5	13.2	2.7	Monn <i>et al.</i> , 1999
5	Davos	78.0	18.0	4.0	Monn <i>et al.</i> , 1999
6	Charleston, WV	55.0	-	-	Lewis <i>et al.</i> , 1980
7	St Louis, MO	55.0	-	-	Spengler <i>et al.</i> , 1983
8	Leeds, UK	63.0	-	-	Willison <i>et al.</i> , 1985
9	Detroit, MI	47.0	-	-	Wolf <i>et al.</i> , 1985
10	Sao Palo, Brazil	81.0	-	-	Orsini <i>et al.</i> , 1986
11	Chicago, IL	43.0	-	-	Rashid <i>et al.</i> , 1988
12	Riyadh, Saudi Arabia	58.0	-	-	El-Shobokkshy <i>et al.</i> , 1990
13	Kashima, Japan	50.0	50.0	-	Okamoto <i>et al.</i> , 1991
14	Long Beach, C.A.	60.0	-	-	Wolf <i>et al.</i> , 1985
15	Claremont, CA	73.0	-	-	Wolf <i>et al.</i> , 1985
16	Kuala Lumpur, Malaysia	68.0	-	-	Rashid <i>et al.</i> , 1995
17	Brisbane, Australia	16.5	83.5	-	Chan <i>et al.</i> , 1997
18	Watertown, Boston	66.9	33.1	-	Thurston <i>et al.</i> , 1985
19	IIT, Mumbai	74.3	22.8	2.9	Sharma <i>et al.</i> , 1992
20	Bhandup, Mumbai	65.3	29.5	5.2	Sharma <i>et al.</i> , 1992

relative abundance making it difficult for us to relate our findings with that of the other researchers. However, we observed from Table 4.5 that excluding Brisbane, Australia, the concentration of fine particle group of PM_{2.5} ranged from 47% at Detroit to 84.5% at Wald. At Brisbane, the PM_{2.5} was observed as low as 16.5%. In Mumbai, the PM_{2.5} concentration at traffic activity related area was 74.3% (IIT) while it was 65.3% at industrial location (Bhandup). The relative abundance of PM_{2.5} under the current study (Table 4.4) ranged from a 59.1% at CB locations to 80.9% at H locations while it dropped to 63.0% at IN locations thus showing similarities in the concentration of PM_{2.5} though the techniques used for assessment

of particle size distribution patterns were different. The similarities were pronounced in case of $PM_{2.5}$ concentrations at Mumbai and that obtained in this study. The concentration of PM_{10} (Table 4.5) excluding Kashima and Brisbane (where it was 50.0% and 83.5% respectively) ranged from 13.2% at Aarau to 33.1% at Watertown. The concentration of PM_{10} in Shillong (Table 4.4) ranged from 10.5% at TIG0 to 33.5% at CB locations. Again, our findings of PM_{10} concentrations showed similarities with that observed by the other workers (Table 4.5). The $PM_{>10}$ concentrations (Table 4.5) ranged from 2.7% at Wald to 5.4% at Geneva. The $PM_{>10}$ concentrations at Mumbai were 2.9% and 5.2% at IIT and Bhandup respectively. $PM_{>10}$ concentration in our study (Table 4.4) ranged from 2.6% at TIG0 to 8.2% at MP locations. The highest concentration of $PM_{>10}$ was observed at IN locations where it had been 11.4%. Similarities in our findings of $PM_{>10}$ concentrations were evident in this case as well. In general, we see that though the methodologies and concepts used by us for determination of the particle size distribution patterns were different than those adopted by the other researchers but our findings showed similar patterns in particle size distributions in Shillong.

4.5.2 Temporal variations in solid particle size distributions

Temporal variations in relative abundance of $PM_{2.5}$ at CB locations (Table A.4.1) showed that the concentration of $PM_{0.44}$ ranged from 8.9% at CB1 to 21.1% at CB2 with the peak value of 27.8% also at CB2. The standard deviation (SD) for $PM_{0.44}$ was also fairly high (about 10%) signifying high temporal variations in this particle size fraction. $PM_{0.88}$ ranged from 14.9% at CB3 to 20.6% at CB1 with the

peak value of 26.6% also at CB1. The lowest concentration of 13.9% for $PM_{1.77}$ was obtained at CB2 while the highest of 18.2% had been at CB1 with a peak value of 23.8% again at CB1. Similarly, the concentration of $PM_{2.6}$ ranged from 7.6% at CB2 to 11.4% at CB1 with a peak value of 15.2% also at CB1. Thus, we observed that the concentration of $PM_{0.44}$ was highest at CB2, while the concentration of $PM_{0.88}$, $PM_{1.77}$ and $PM_{2.6}$ were highest at CB1. The occurrence of highest concentration of $PM_{0.44}$ at CB2 seemed to be due to its situation in the valley where the wash out due to wind appeared to be less prominent in comparison with the other locations of CB1 and CB3 that were situated on the hilltops.

Table 4.6 Temporal variations in relative abundance (%) of solid particles at CB locations

Location Code	Cum. $PM_{2.5}$		PM_5		PM_{10}		$PM_{>10}$		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
CB1	59.0±4.0	61.8	22.0±8.7	26.1	12.1±0.7	11.6	7.1±3.9	9.8	2
CB2	58.7±12.0	67.2	17.2±4.5	20.4	14.6±2.4	12.9	9.5±5.0	13.0	2
CB3	59.6±8.9	65.9	20.4±6.3	24.8	14.3±3.1	12.1	5.8±0.4	6.1	2

The temporal variations in relative abundance of cumulative $PM_{2.5}$, PM_5 , PM_{10} and $PM_{>10}$ at CB locations are shown in Table 4.6. Concentration of cumulative $PM_{2.5}$ ranged from 58.7% at CB2 to 59.6% at CB3 with the peak value of 67.2% at CB2. As such, the variations in $PM_{2.5}$ concentrations among CB locations were not very substantial. The concentration of PM_5 ranged from 17.2% at CB2 to 22.0% at CB1 with a peak value of 26.1% also at CB1. The concentration of PM_5 was found to be slightly more at CB1 and CB3 in comparison with the CB2. As the size group of PM_5 at CB locations supposed to be mostly consisted of biogenic

particles like pollens, spores and fine grinded leaves, it was not unlikely that the free wind movements at the hills (CB1 and CB3) facilitated the release of these particles thereby recording increase in their concentrations. The concentration of PM_{10} ranged from 12.1% at CB1 to 14.6% at CB2 with a peak value of 12.9% also at CB2. $PM_{>10}$ ranged from 5.8% at CB3 to 9.5% at CB2 with a peak value of 13.0% also at CB2. The concentration of the different particle size groups at CB locations showed an explicit decreasing trend from fine particles ($PM_{2.5}$) to the coarse particles ($PM_{>10}$).

The temporal variations in relative abundance of $PM_{2.5}$ at MP locations (Table A.4.2) showed that $PM_{0.44}$ concentration ranged from 6.8% at MP11 to 26.2% at MP6 with the peak value of 30.1% at MP1. The range of SD for $PM_{0.44}$ was also fairly high (1.8% to 13.4%) for all the locations signifying high temporal variability in concentrations of this particle size fraction. The MP11, where such low $PM_{0.44}$ concentration (6.8%) was observed, had been a high commercial activity area with low traffic activities as ρ_T during sampling hours was only 416 vehicles (Table A.1.1). Whereas, the MP6, where highest $PM_{0.44}$ concentration (26.2%) was recorded, had been located on the highway with high traffic activities as the ρ_T during sampling was above 3000 vehicles. $PM_{0.88}$ concentration ranged from 11.0% at MP11 to 34.3% at MP3 with the peak value of 35.5% also at MP3. The highest $PM_{0.88}$ concentration location of MP3 was also located on the highway with ρ_T above 2000 vehicles. The lowest concentration of 15.7% for $PM_{1.77}$ was obtained at MP10 while the highest of 23.0% was recorded at MP5 with a peak value of 25.9% at MP9. The variations in concentration of $PM_{1.77}$ were not as significant as observed for $PM_{0.44}$ and $PM_{0.88}$. The concentration of $PM_{2.6}$ ranged from 6.9% at MP3 to

15.9% at MP7 with a peak value of 23.6% also at MP7, which was a high commercial activity area located on highway.

The temporal variations in relative abundance of solid particles of other size groups at MP locations are given in Table 4.7. The concentration of cumulative PM_{2.5} ranged from 42.0% at MP11 to 84.3% at MP3 with the peak value of 88.8% also at MP3. As such, the variations in cumulative PM_{2.5} concentrations among MP locations were quite significant. PM₅ concentration ranged from 8.5% at MP3 to 22.2% at MP4 with a peak value of 26.6% also at MP4. PM₁₀ ranged from 4.4% at

Table 4.7 Temporal variations in relative abundance (%) of solid particles at MP locations

Location Code	Cum. PM _{2.5}		PM ₅		PM ₁₀		PM _{>10}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
MP1	73.7 $\pm$ 8.2	82.2	14.1 $\pm$ 7.0	21.4	8.4 $\pm$ 1.0	9.1	3.8 $\pm$ 0.7	4.4	3
MP2	76.6 $\pm$ 13.3	87.4	11.2 $\pm$ 7.5	19.6	7.6 $\pm$ 4.1	12.1	4.4 $\pm$ 1.8	6.5	3
MP3	84.3 $\pm$ 5.9	88.8	8.5 $\pm$ 4.1	11.4	4.4 $\pm$ 1.4	5.4	2.9 $\pm$ 0.4	3.2	2
MP4	58.6 $\pm$ 17.0	70.6	22.2 $\pm$ 6.3	26.6	12.3 $\pm$ 6.9	17.2	7.0 $\pm$ 3.8	9.7	2
MP5	72.4 $\pm$ 1.1	73.2	16.8 $\pm$ 0.2	16.9	6.8 $\pm$ 0.6	7.2	4.1 $\pm$ 0.8	4.6	2
MP6	79.3 $\pm$ 0.49	79.6	9.9 $\pm$ 0.1	9.9	6.0 $\pm$ 0.2	6.1	5.0 $\pm$ 0.6	5.4	2
MP7	73.5 $\pm$ 5.7	79.6	12.5 $\pm$ 2.9	15.0	8.8 $\pm$ 2.6	11.6	5.2 $\pm$ 1.4	6.9	3
MP8	57.1 $\pm$ 3.8	60.8	17.1 $\pm$ 3.0	18.9	17.1 $\pm$ 1.7	19.0	8.9 $\pm$ 0.3	9.7	3
MP9	56.2 $\pm$ 28.6	79.9	12.9 $\pm$ 4.5	17.9	16.2 $\pm$ 14.0	32.0	14.6 $\pm$ 10.2	25.6	3
MP10	55.9 $\pm$ 12.3	64.6	17.9 $\pm$ 6.8	22.7	14.3 $\pm$ 3.8	16.9	12.0 $\pm$ 1.7	13.2	2
MP11	42.0 $\pm$ 3.3	44.3	19.3 $\pm$ 1.8	20.5	21.9 $\pm$ 2.1	23.3	16.9 $\pm$ 0.6	17.3	2
MP12	54.8 $\pm$ 7.4	60.0	17.0 $\pm$ 0.6	17.4	15.7 $\pm$ 3.3	18.0	12.6 $\pm$ 4.6	15.8	2
MP13	64.7 $\pm$ 5.5	68.6	15.3 $\pm$ 0.6	15.7	11.5 $\pm$ 2.5	13.2	8.6 $\pm$ 3.8	11.2	2

MP3 to 21.9% at MP11 with a peak value of 32.0% also at MP9. PM_{>10} ranged from 2.9% at MP3 to 16.9% at MP11 with a peak value of 17.3% also at MP11. The increase in concentration of PM₅, PM₁₀ and PM_{>10} at certain MP locations appeared to be due to increase in concentration of coarse dust particles because of the

resuspension of dust due to increased traffic, pedestrian and commercial activities.

The temporal variations in relative abundance of $PM_{2.5}$ at MU locations (Table A.4.3) showed that $PM_{0.44}$ concentration ranged from 12.0% at MU3 to 30.1% at MU2 with the peak value of 42.3% at MU6. The range of SD for $PM_{0.44}$ was also quite high (0.1% to 13.6%) signifying high temporal variations in concentrations of this particle size fraction. The MU3, where low $PM_{0.44}$ concentration (12.0%) was obtained, had been located in a high commercial activity area of the city. Whereas, the MU2, where highest $PM_{0.44}$ concentration (30.1%) was recorded, had been located on the highway with high traffic activities as ρ_T during sampling was about 2800 vehicle. $PM_{0.88}$ concentration ranged from 12.2% at MU5 to 32.5% at MU1 with the peak value of 36.2% also at MU1. The highest $PM_{0.88}$ concentration location of MU1 was also situated on the highway with ρ_T of above 2300 vehicles. The lowest concentration of 13.9% for $PM_{1.77}$ was obtained at MU4 while the highest of 20.8% was found at MU10 with a peak value of 23.3% also at MU10. The concentration of $PM_{2.6}$ ranged from 7.3% at MU7 to 11.6% at MU11 with a peak value of 13.4% at MU1.

The temporal variations in relative abundance of solid particles of other size groups at MU locations are provided at Table 4.8. Concentration of cumulative $PM_{2.5}$ ranged from 53.6% at MU3 to 80.4% at MU2 with the peak value of 85.8% also at MU2. As such, the variations in $PM_{2.5}$ concentrations among MU locations were also very significant. The concentration of PM_5 ranged from 9.0% at MU2 to 18.7% at MU4 with a peak value of 22.4% also at MU3. PM_{10} ranged from 6.3% at MU1 and MU2 to 17.2% at MU5 with a peak value of 18.1% at MU3. $PM_{>10}$ ranged

from 3.7% at MU10 to 13.4% at MU3 with a peak value of 15.4% also at MU3. A slight decrease in maximum concentration of $PM_{2.5}$, PM_{10} and $PM_{>10}$ was noted in case of MU locations in comparison with MP locations.

Table 4.8 Temporal variations in relative abundance (%) of solid particles at MU locations

Location Code	Cum. $PM_{2.5}$		$PM_{2.5}$		PM_{10}		$PM_{>10}$		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
MU1	74.7±1.9	76.0	14.7±1.6	15.8	6.3±0.4	6.5	4.3±0.7	4.8	2
MU2	80.4±7.6	85.8	9.0±1.6	10.1	6.3±2.4	8.0	4.3±3.5	6.8	2
MU3	53.6±9.0	62.5	17.3±4.4	22.4	15.6±2.9	18.1	13.4±3.0	15.4	3
MU4	67.6±16.9	79.5	18.7±1.6	19.8	8.8±5.8	12.9	5.0±3.3	7.3	2
MU5	58.1±0.3	58.3	15.2±2.7	17.1	17.2±0.9	17.8	9.5±2.2	11.0	2
MU6	77.7±5.8	84.1	11.2±2.2	13.8	6.9±1.8	8.2	4.2±2.7	6.2	3
MU7	66.6±9.0	75.5	16.3±4.6	20.8	9.3±0.9	10.0	7.7±3.5	11.6	3
MU8	66.3±9.0	72.6	15.7±8.2	21.5	11.7±2.1	13.2	6.3±0.8	6.8	2
MU9	68.9±4.1	71.8	14.3±2.6	16.1	10.1±0.7	10.6	6.7±0.7	7.2	2
MU10	77.4±2.8	80.4	12.2±2.9	15.2	6.8±0.7	7.5	3.7±1.9	5.7	3
MU11	73.3±6.0	78.6	12.6±2.2	14.2	8.6±2.8	11.8	5.4±2.2	7.9	3

The temporal variations in relative abundance of $PM_{2.5}$ at HP locations (Table A.4.4.) showed that the concentration of $PM_{0.44}$ ranged from 17.9% at HP6 to 29.3% at HP9 with the peak value of 49.4% at HP7. The range of SD for $PM_{0.44}$ was also quite high (0.1% to 19.4%) again signifying high temporal variations in concentrations of this particle size fraction. The HP6, where low $PM_{0.44}$ concentration (17.9%) was obtained, had been located near secretarial buildings. Though the traffic concentration at this location was above 6600 vehicles during sampling but it had a one-way traffic system that helped in easy flow of the passage. The HP9, where highest $PM_{0.44}$ concentration (29.3%) was recorded, had been located on the highway. This location was marked with the highest traffic activities,

as ρ_T during sampling was above 10,000 vehicles. The concentration of $PM_{0.88}$ ranged from 19.8% at HP4 to 25.9% at HP2 with the peak value of 34.1% at HP6. The highest $PM_{0.88}$ concentration location of HP2 had been located on the highway with ρ_T of about 5200 vehicles during sampling. The lowest concentration of 16.8% for $PM_{1.77}$ was obtained at HP11 while the highest of 25.2% was at HP2 and HP13 with a peak value of 29.9% also at HP13. The concentration of $PM_{2.6}$ ranged from 7.3% at HP7 to 10.2% at HP1 with a peak value of 13.5% at HP8.

Table 4.9 Temporal variations in relative abundance (%) of solid particles at HP locations

Location Code	Cum. $PM_{2.5}$		PM_5		PM_{10}		$PM_{>10}$		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
HP1	76.6 $\pm$ 3.7	79.2	11.5 $\pm$ 4.2	14.5	8.0 $\pm$ 0.7	8.5	3.9 $\pm$ 0.4	4.2	2
HP2	75.7 $\pm$ 2.3	77.3	14.1 $\pm$ 1.7	15.3	7.0 $\pm$ 0.9	7.6	3.2 $\pm$ 1.6	4.3	2
HP3	72.8 $\pm$ 9.7	80.9	14.0 $\pm$ 3.7	18.2	8.8 $\pm$ 4.7	13.8	4.4 $\pm$ 1.3	5.8	3
HP4	66.2 $\pm$ 5.4	71.8	14.3 $\pm$ 5.1	20.0	11.9 $\pm$ 2.5	13.6	7.7 $\pm$ 2.2	10.2	3
HP5	79.1 $\pm$ 4.2	82.0	10.1 $\pm$ 2.1	11.5	6.8 $\pm$ 0.4	7.1	4.1 $\pm$ 1.8	5.4	2
HP6	69.2 $\pm$ 17.2	85.5	13.3 $\pm$ 5.1	17.6	10.7 $\pm$ 6.7	17.7	6.8 $\pm$ 8.4	16.5	3
HP7	76.2 $\pm$ 6.2	83.1	16.0 $\pm$ 3.7	19.2	5.4 $\pm$ 1.7	7.0	4.5 $\pm$ 0.9	5.1	3
HP8	66.4 $\pm$ 0.6	66.9	13.1 $\pm$ 0.7	13.8	12.9 $\pm$ 1.5	14.4	7.6 $\pm$ 1.5	8.9	3
HP9	79.1 $\pm$ 14.8	95.1	18.0 $\pm$ 7.6	24.3	1.8 $\pm$ 0.6	2.4	1.1 $\pm$ 0.4	1.3	3
HP10	72.2 $\pm$ 16.5	83.8	12.1 $\pm$ 8.0	17.7	9.6 $\pm$ 4.4	12.7	6.2 $\pm$ 4.1	9.1	2
HP11	75.2 $\pm$ 2.6	77.1	9.5 $\pm$ 1.9	11.3	9.2 $\pm$ 5.7	14.3	6.1 $\pm$ 3.3	8.9	3
HP12	75.7 $\pm$ 7.3	83.7	8.9 $\pm$ 0.6	9.4	7.6 $\pm$ 0.8	8.1	7.8 $\pm$ 3.5	11.8	3
HP13	78.0 $\pm$ 15.4	92.6	7.9 $\pm$ 3.1	10.7	7.1 $\pm$ 6.7	14.3	6.4 $\pm$ 5.9	12.9	3

The temporal variations in relative abundance of solid particles of other size groups at HP locations are provided at Table 4.9. Concentration of cumulative $PM_{2.5}$ ranged from 66.2% at HP4 to 79.1% at HP5 and HP9 with the peak value of 95.1% at HP9. PM_5 ranged from 7.9% at HP13 to 18.0% at HP9 with a peak value of 24.3% also at HP9. PM_{10} ranged from 5.4% at HP7 to 12.9% at HP8 with a peak

value of 17.7% at HP6. $PM_{>10}$ ranged from 1.1% at HP9 to 7.8% at HP8 with a peak value of 16.5% also at HP6. Moderate variations in maximum concentration of PM_5 , PM_{10} and $PM_{>10}$ were observed in comparison to MP and MU locations.

The temporal variations in relative abundance of $PM_{2.5}$ at HU locations (Table A.4.5) indicated that the concentration of $PM_{0.44}$ ranged from 16.5% at HU4 to 29.0% at HU6 with the peak value of 40.3% also at HU6. The range of SD for $PM_{0.44}$ was high (0.5 to 17.8%) indicating high temporal variations in concentrations of $PM_{0.44}$. The HU4, where low $PM_{0.44}$ concentration (16.5%) was obtained, had been located on highway but had fairly open surroundings in southern direction. The traffic concentration at this location was about 4000 vehicles during sampling, which was the lowest recorded at HU locations. The HU6, where highest $PM_{0.44}$ concentration (29.0%) was recorded, had been located near assembly. This location had ρ_T of above 5000 vehicles during sampling. $PM_{0.88}$ concentration ranged from 21.9% at HU11 to 29.2% at HU2 with the peak value of 31.6% also at HU2. The variations in $PM_{0.88}$ concentrations were not very high. The lowest concentration of 16.9% for $PM_{1.77}$ was obtained at HU6 while the highest of 22.1% was recorded at HU11 with a peak value of 25.8% also at HU7. $PM_{2.6}$ concentration ranged from 6.3% at HU8 to 12.7% at HU3 with a peak value of 14.3% also at HU3.

The temporal variations in relative abundance of solid particles of other size groups at HU locations are provided at Table 4.10. Concentration of cumulative $PM_{2.5}$ ranged from 70.7% at HU11 to 81.5% at HU2 with the peak value of 88.2% also at HU2. PM_5 concentration ranged from 9.2% at HU2 to 14.3% at HU11 with a peak value of 19.7% at HU6. PM_{10} ranged from 6.7% at HU7 to 10.3% at HU4 with

a peak value of 13.5% at HU4. $PM_{>10}$ concentration ranged from 2.3% at HU3 to 7.1% at HU11 with a peak value of 9.6% also at HU11. A decrease in maximum concentration of PM_5 , PM_{10} and $PM_{>10}$ was observed in case of HU locations in comparison to MP, MU and HP locations.

Table 4.10 Temporal variations in relative abundance (%) of solid particles at HU locations

Location	Cum. $PM_{2.5}$		PM_5		PM_{10}		$PM_{>10}$		Sample Size (N)
Code	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
HU1	76.0 $\pm$ 4.7	79.3	11.6 $\pm$ 0.1	11.7	8.1 $\pm$ 4.2	11.0	4.3 $\pm$ 0.3	4.5	2
HU2	81.5 $\pm$ 9.5	88.2	9.2 $\pm$ 3.7	11.8	6.9 $\pm$ 4.7	10.2	2.4 $\pm$ 1.1	3.2	2
HU3	78.7 $\pm$ 4.3	81.7	10.8 $\pm$ 0.9	11.4	8.2 $\pm$ 2.2	9.7	2.3 $\pm$ 1.3	3.2	2
HU4	72.9 $\pm$ 11.6	81.1	11.7 $\pm$ 2.7	13.6	10.3 $\pm$ 4.5	13.5	5.1 $\pm$ 4.4	8.2	2
HU5	74.9 $\pm$ 11.4	85.1	10.4 $\pm$ 5.7	16.1	9.5 $\pm$ 3.4	12.9	5.2 $\pm$ 2.5	7.0	3
HU6	75.4 $\pm$ 10.1	82.6	12.4 $\pm$ 6.4	19.7	8.6 $\pm$ 3.4	12.4	3.6 $\pm$ 0.8	4.1	3
HU7	79.1 $\pm$ 7.5	87.4	10.0 $\pm$ 1.3	11.2	6.7 $\pm$ 3.0	9.6	4.2 $\pm$ 2.7	7.2	3
HU8	74.0 $\pm$ 4.2	76.9	12.9 $\pm$ 3.3	15.2	7.7 $\pm$ 1.8	8.9	5.4 $\pm$ 1.0	6.1	2
HU9	75.3 $\pm$ 6.7	82.3	11.4 $\pm$ 1.0	12.3	8.6 $\pm$ 2.9	11.7	4.6 $\pm$ 3.7	7.2	3
HU10	75.3 $\pm$ 1.4	76.3	13.3 $\pm$ 0.1	13.4	6.9 $\pm$ 0.8	7.4	4.6 $\pm$ 2.4	6.3	2
HU11	70.7 $\pm$ 15.1	81.3	14.3 $\pm$ 6.5	18.9	8.0 $\pm$ 4.8	11.4	7.1 $\pm$ 3.5	9.6	2

The temporal variations in relative abundance of $PM_{2.5}$ at TIF (Table A.4.6) showed that the highest concentration of 30.7% for $PM_{0.44}$ was found at TIF0. A gradual decrease in $PM_{0.44}$ concentration was observed at locations in north direction. The minimum $PM_{0.44}$ concentration of 20.5% was observed at TIFN3. In south direction, first the concentration of $PM_{0.44}$ dropped at TIFS1 then it showed a gradual increase. The concentration of $PM_{0.88}$ was highest at TIFN1, TIF0 and TIFS1 where it varied from 26.0% to 28.8%. The locations of TIFN2, TIFN1, TIFS2 and TIFS1 showed a gradual decrease in comparison with the TIF0. While the high concentrations of $PM_{0.88}$ at TIF0 seemed to be due to traffic related activities, almost

similar $PM_{0.88}$ concentrations at TIFN1 and TIFS1 appeared to be because of the coagulation of finer particles to this size group. The $PM_{1.77}$ concentration did not show any patterns as it varied from location to location. The lowest $PM_{1.77}$ concentration of 12.0% was observed at TIFS1 while the highest of 21.4% was recorded at TIFN2. Like $PM_{1.77}$, $PM_{2.6}$ also did not show any patterns. The concentration of $PM_{2.6}$ ranged from 5.3% at TIFS3 to 11.1% at TIFN3.

The temporal variations in relative abundance of solid particles of other size groups at TIF locations are provided at Table 4.11. Concentration of cumulative $PM_{2.5}$ was highest at TIFN1 and TIF0 (about 80%) while it decreased to 71.0% at TIFN3 and 76.5% at TIFS3. PM_5 concentration was minimum at TIFN1 (7.7%) while the highest of 13.7% was observed at TIFN2. In general, the concentration of PM_5 was more at across directions in comparison with the highway location of traffic intersections. The lowest concentration of 5.0% of PM_{10} was observed at TIF0

Table 4.11 Temporal variations in relative abundance (%) of solid particles at TIF locations

Location Code	Cum. $PM_{2.5}$		PM_5		PM_{10}		$PM_{>10}$		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIFN3	71.0 $\pm$ 11.4	79.0	11.9 $\pm$ 4.6	15.1	11.7 $\pm$ 6.0	15.9	5.6 $\pm$ 0.8	6.1	2
TIFN2	75.8 $\pm$ 0.4	76.1	13.7 $\pm$ 0.3	13.9	6.5 $\pm$ 0.1	6.6	4.0 $\pm$ 0.9	4.6	2
TIFN1	80.3 $\pm$ 3.1	82.5	7.7 $\pm$ 0.3	7.9	7.3 $\pm$ 3.5	9.8	4.7 $\pm$ 0.1	4.8	2
TIF0	79.3 $\pm$ 11.1	87.1	9.7 $\pm$ 6.7	14.4	5.0 $\pm$ 1.9	6.3	6.1 $\pm$ 2.7	8.0	2
TIFS1	74.2 $\pm$ 12.2	82.8	10.0 $\pm$ 2.0	11.4	9.2 $\pm$ 4.9	12.6	6.7 $\pm$ 5.3	10.4	2
TIFS2	76.3 $\pm$ 0.7	76.8	10.4 $\pm$ 3.0	12.5	7.2 $\pm$ 1.1	7.9	6.2 $\pm$ 2.6	8.0	2
TIFS3	76.5 $\pm$ 7.4	81.7	9.9 $\pm$ 1.7	11.1	11.7 $\pm$ 1.9	13.0	4.9 $\pm$ 3.8	7.5	2

while the highest of 11.7% was observed at TIFN3 and TIFS3. The variations in concentration of $PM_{>10}$ were not that significant as it ranged from 4.0% at TIFN2 to 6.7% at TIFS3.

The temporal variations in relative abundance of $PM_{2.5}$ at TIB locations (Table A.4.7) showed that the highest concentration of 25.5% for $PM_{0.44}$ was observed at TIBN3 while it was 24.6% at TIB0. The lowest $PM_{0.44}$ concentration of 12.1% was obtained at TIBS1. TIB0 had been comparatively open location with thick vegetation at adjoining areas and across locations. Low concentration of $PM_{0.44}$ appeared to be due to the fact the build up of fine particles was comparatively less due to its open surroundings. Again no definite patterns for $PM_{0.88}$ concentrations were observed for TIB locations. The concentration of $PM_{0.88}$ was highest at TIBN1 where it was 28.0% while the lowest of 17.8% was recorded at TIBN0. The variations in $PM_{1.77}$ concentration were not that significant as it ranged from 15.0% at TIBS3 to 19.3% at TIB0. The concentration of $PM_{2.6}$ ranged from 7.1% at TIBS3 to 12.7% at TIB0.

The temporal variations in relative abundance of solid particles of other size groups at TIB locations are provided at Table 4.12. The highest concentration of 79.0% for cumulative $PM_{2.5}$ was observed at TIBS2 while the lowest of 70.9% was found at TIBN2. PM_5 concentration was found to be minimum at TIB0 (9.9%). Though, no definite pattern had been observed for PM_5 concentrations at TIB locations but it was evident that it increased on across locations and a maximum value of 14.1% was observed at TIBS1 and TIBN3. The lowest concentration of 7.5% of PM_{10} was observed at TIBN1 and TIBS2 while the highest concentration of 14.5% was observed at TIBS2. The concentration of $PM_{>10}$ ranged from 4.0% at TIBS1 to 10.7% at TIBN1.

Table 4.12 Temporal variations in relative abundance (%) of solid particles at TIB locations

Location	Cum. PM _{2.5}		PM ₅		PM ₁₀		PM _{>10}		Sample Size (N)
Code	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
TIBN3	71.0±1.1	71.7	14.1±4.4	17.2	10.2±1.6	11.3	4.0±2.3	5.6	2
TIBN2	70.9±2.4	72.6	10.7±2.0	12.1	11.0±0.5	11.3	9.6±2.7	11.5	2
TIBN1	76.3±3.3	78.6	11.6±2.2	13.1	7.5±1.9	8.8	10.7±5.0	14.2	2
TIB0	74.4±12.3	83.1	9.9±3.6	12.4	9.6±4.8	13.0	2.6±2.3	4.2	2
TIBS1	58.3±30.7	80.0	14.1±4.6	17.5	14.5±13.1	23.8	4.0±1.6	5.1	2
TIBS2	79.0±7.6	84.4	10.3±4.7	13.6	7.5±1.8	8.7	5.8±0.5	6.1	2
TIBS3	73.8±4.8	77.2	12.9±0.6	13.3	8.0±2.9	10.0	7.5±2.3	9.1	2

The temporal variations in relative abundance of PM_{2.5} at TIG locations (Table A.4.8) indicated highest concentration of 32.5% for PM_{0.44} at TIG0. A slight decrease in PM_{0.44} concentration was observed at locations in across directions but it was not that significant for TIGS2 and TIGN3. Both the locations of TIGS2 and TIGN3 were in residential areas. While stack of the boilers using coal as fuel (from a hospital) had been close to TIGN3, some bakeries were close to the TIGS2 that also used coal as fuel. This seemed to be the reason for elevated PM_{0.44} concentrations. The highest concentration of 30.7% for PM_{0.88} was observed at TIG0 while the lowest concentration of 17.3% was recorded at TIGS2. Like PM_{0.88}, PM_{1.77} concentration also did not show any patterns as it also varied from location to location. The lowest PM_{1.77} concentration of 12.7% was observed at TIGN1 while the highest of 15.9% was recorded at TIGS1. The variations in PM_{2.6} concentrations at across locations and on traffic intersection were not very significant. PM_{2.6} concentration ranged from 6.6% at TIGN1 to 9.3% at TIG0.

The temporal variations in relative abundance of solid particles of other size groups at TIG locations are provided at Table 4.13. The highest concentration of

86.9% for cumulative $PM_{2.5}$ was observed at TIG0 while the lowest of 64.7% was recorded at TIGN2. PM_5 concentration was minimum at TIG0 (6.6%) while the highest of 14.2% was observed at TIGS2. As observed in cases of TIF0 and TIB0, generally the concentration of PM_5 was more at across locations in comparison with the highway locations. The lowest concentration of 3.9% of PM_{10} was observed at TIG0 while the highest concentration of 12.3% was observed at TIGN2. $PM_{>10}$ concentration ranged from 2.6% at TIG0 to 10.7% at TIGN1.

Table 4.13 Temporal variations in relative abundance (%) of solid particles at TIG locations

Location Code	Cum. $PM_{2.5}$		PM_5		PM_{10}		$PM_{>10}$		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIGN3	79.7 $\pm$ 12.7	88.7	11.2 $\pm$ 8.3	17.1	5.1 $\pm$ 2.1	6.6	4.0 $\pm$ 2.1	5.6	2
TIGN2	64.7 $\pm$ 13.7	74.3	13.5 $\pm$ 5.3	17.2	12.3 $\pm$ 5.7	16.3	9.6 $\pm$ 2.7	11.5	2
TIGN1	65.1 $\pm$ 5.7	69.1	13.4 $\pm$ 2.8	15.3	10.9 $\pm$ 3.5	13.3	10.7 $\pm$ 5.0	14.2	2
TIG0	86.9 $\pm$ 10.1	94.0	6.6 $\pm$ 3.8	9.3	3.9 $\pm$ 3.8	6.6	2.6 $\pm$ 2.3	4.2	2
TIGS1	77.7 $\pm$ 1.1	78.4	11.9 $\pm$ 0.2	12.0	6.7 $\pm$ 2.9	8.7	4.0 $\pm$ 1.6	5.1	2
TIGS2	68.0 $\pm$ 4.7	71.3	14.2 $\pm$ 3.0	16.3	12.2 $\pm$ 2.3	13.8	5.8 $\pm$ 0.5	6.1	2
TIGS3	73.1 $\pm$ 0.4	73.3	10.1 $\pm$ 0.2	10.2	9.4 $\pm$ 1.6	10.5	7.5 $\pm$ 2.3	9.1	2

The temporal variations in relative abundance of $PM_{2.5}$ at H and IN locations (Table A.4.9) showed that the concentration of $PM_{0.44}$ at H1 and H2 locations was 27.8% and 25.2% respectively that dropped to 16.5% and 20.1% respectively at IN1 and IN2 locations. The drop was more in case of IN1, which was a residence. This indicated that chances of fine particles to enter inside the residences were less as people keep doors and windows closed during cold season of winter while the same was not the case with the shops. Similarly, the concentration of $PM_{0.88}$ (31.1% and 25.2% at H1 and H2 respectively) and $PM_{1.77}$ (19.0% and 17.4% at H1 and H2

respectively) also dropped at IN locations to 18.6% and 24.1% (IN1 and IN2 respectively) for $PM_{0.88}$ and 15.2% and 16.9% (IN1 and IN2 respectively) for $PM_{1.77}$. The drop in concentration of $PM_{2.6}$ was not that significant. The $PM_{2.6}$ concentration at H1 and H2 was 7.9% and 8.2% at H1 and H2 locations respectively that dropped to 7.2% and 7.7% respectively at IN1 and IN2 locations.

The temporal variations in relative abundance of solid particles of other size groups H and IN locations are given in Table 4.14. The concentration of cumulative $PM_{2.5}$ was 85.8% and 76.0% at H1 and H2 locations. It dropped to 57.4% and 68.7% at IN1 and IN2 locations. The possible reasons for this drop in $PM_{2.5}$ were explained at the above paragraph. Contrary to the observations made for $PM_{2.5}$, the concentration of PM_5 , PM_{10} and $PM_{>10}$ showed increasing trends at IN locations in comparison with H locations. The concentration of PM_5 at H1 and H2 was 6.2% and 11.3% respectively which increased to 14.9% and 11.7% respectively at IN1 and

Table 4.14 Temporal variations in relative abundance (%) of solid particles at H and IN locations

Location Code	Cum. $PM_{2.5}$		PM_5		PM_{10}		$PM_{>10}$		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
H1	85.8±3.5	88.2	6.2±0.6	6.6	5.4±2.5	7.1	3.7±0.1	3.8	2
H2	76.0±6.2	80.3	11.3±1.8	12.5	7.5±4.5	10.7	6.0±2.3	7.6	2
IN1	57.4±18.5	70.4	14.9±3.3	17.2	14.3±6.9	19.1	13.6±8.3	19.4	2
IN2	68.7±13.3	78.1	11.7±6.4	16.2	10.3±3.0	12.4	9.3±3.8	12.0	2

IN2. The concentration of PM_{10} at H1 and H2 was 5.4% and 7.5% respectively which increased to 14.3% and 10.3% respectively at IN1 and IN2. Likewise, The concentration of $PM_{>10}$ at H1 and H2 was 3.7% and 6.0% respectively which

increased to 13.6% and 9.3% respectively at IE1 and IE2.

The temporal variations in relative abundance of $PM_{2.5}$ at IE locations (Table A.4.10) indicated quite significant variations in $PM_{0.44}$ concentration at IE1 and IE2. Concentration of $PM_{0.44}$ at IE1 and IE2 was 12.0% and 30.0%. Though, IE1 had been an industrial estate, it had no air polluting industries. Moreover, it had thick pine forest around and, as such, the characteristics of IE1 varied with that of IE2 considerably. The variations in concentration of $PM_{0.88}$, $PM_{1.77}$ and $PM_{2.6}$ were not that prominent as it ranged from 19.0% to 25.6% respectively for $PM_{0.88}$, 21.3% to 18.6% for $PM_{1.77}$ and 10.7% to 5.5% for $PM_{2.6}$.

The temporal variations in relative abundance of solid particles of other size groups at IE locations are given in Table 4.15. Concentration of cumulative $PM_{2.5}$ ranged from 62.9% at IE1 to 79.6% at IE2. As explained in paragraph above, there were marked dissimilarities between IE1 and IE2 that led to the significant variations in cumulative $PM_{2.5}$ concentrations. The concentration of PM_5 varied from

Table 4.15 Temporal variations in relative abundance (%) of solid particles at IE locations

Location Code	Cum. $PM_{2.5}$		PM_5		PM_{10}		$PM_{>10}$		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
IE1	62.9±6.7	67.6	17.1±0.4	17.4	10.9±2.3	12.5	9.2±4.8	12.6	2
IE2	79.6±1.9	80.9	9.3±0.1	9.3	8.7±1.2	9.5	2.6±0.9	3.1	2

17.1% at IE1 to 9.3% at IE2. The concentration of PM_{10} at IE1 and IE2 was 10.9% and 8.7% respectively. Likewise, The concentration of $PM_{>10}$ at IE1 and IE2 was 9.2% and 2.6% respectively.

The temporal variations in relative abundance of $PM_{2.5}$ at A locations (Table A.4.11) provided vertical variations in particle size distributions. In general, $PM_{0.44}$ concentration increased from 19.9% at A0 to 23.4% at A5. Excluding A2, where the $PM_{0.44}$ concentration was almost same as A0 location, rest of the locations had recorded higher $PM_{0.44}$ concentrations in comparison to A0. Exceptionally high $PM_{0.44}$ concentration at A4 had been perhaps due to a small restaurant on this floor. Likewise excluding A2 and A4, the concentration of $PM_{0.88}$ also showed increasing trends. The concentration of $PM_{0.88}$ was increased from 25.3% at A0 to 36.1% at A5. Contrary to the patterns observed for $PM_{0.44}$ and $PM_{0.88}$, $PM_{1.77}$ showed decreasing trends from A0 to A5. The concentration of $PM_{1.77}$ was decreased from 17.6% at A0 to 15.7% at A5. $PM_{2.6}$ did not show any patterns and its concentration varied from location to location. The lowest concentration of 2.5% for $PM_{2.6}$ was observed at A5 while the highest of 9.0% was recorded at A1.

Table 4.16 Temporal variations in relative abundance (%) of solid particles at A locations

Location Code	Cum. $PM_{2.5}$		PM_5		PM_{10}		PM_{10}		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
A0	72.3±1.2	73.1	13.4±1.5	14.4	7.3±1.3	8.2	7.2±1.2	8.0	2
A1	71.8±13.1	81.0	10.0±3.6	12.5	9.3±4.5	12.5	9.0±5.1	12.6	2
A2	65.7±4.0	68.5	16.0±5.0	19.5	10.1±0.4	10.3	8.3±1.4	9.3	2
A3	71.1±8.1	76.8	11.3±3.5	13.8	9.4±1.8	10.7	8.3±2.8	10.2	2
A4	70.7±16.1	82.1	11.1±3.0	13.2	10.9±6.7	15.6	7.4±6.4	11.9	2
A5	81.5±5.7	85.5	9.0±2.7	10.9	7.1±2.0	8.5	2.5±1.1	3.2	2

The temporal variations in relative abundance of solid particles of other size groups at A locations are provided in Table 4.16. Concentration of cumulative $PM_{2.5}$ increased from 72.3% at A0 to 81.5% at A5. Excluding A2, a decreasing trend was

observed for PM_5 from A0 to A5. The concentration of PM_5 was 13.4% at A0 and 9.0% at A5. The concentration of PM_{10} varied at various locations and did not show any patterns. The concentration of PM_{10} ranged from 7.1% at A5 to 10.9% at A4. $PM_{>10}$ also showed similar trends as observed for PM_{10} . $PM_{>10}$ ranged from 2.5% at A5 to 9.0% at A1.

4.5.3 Relationship of solid particles with traffic density

Attempts were made earlier by several workers to correlate the atmospheric particulate concentrations with traffic activities. Jones *et al.* (1994) established relationships between the traffic activity with PM_{10} and particle number concentrations in Birmingham, England that correlate closely to the traffic count, responding rapidly to the local traffic conditions. We also made attempts to establish linear relationships between size group of $PM_{2.5}$ and other particle size group of cumulative $PM_{2.5}$, PM_5 , PM_{10} and $PM_{>10}$ with traffic density (Appendix-I, Tables A.1.1 to A.1.4) at MP, MU, HP and HU locations by drawing least-square regression lines. The locations of MP, MU, HP and HU were selected as these locations had distinct traffic patterns. The relationship of the particle size groups with the traffic density was further established by evaluating the Pearson correlation coefficients including pair-wise correlations between MP, MU, HP and HU locations on the basis of solid particle concentrations.

The relationship of $PM_{0.44}$ with TW is provided in the form of mathematical equations (Table 4.17). The relationship of $PM_{0.44}$ and TW at MP location was positive although scattering of points on both sides of the regression lines (Fig. 4.3)

showed some inconsistency in association. R^2 value for $PM_{0.44}$ and TW was moderate (0.36) indicating that about 36% of $PM_{0.44}$ concentrations at MP locations could be explained by TW exhaust emissions. The relationship of $PM_{0.44}$ and TW at MU locations was also positive (Fig. 4.4). R^2 value for $PM_{0.44}$ and TW here was almost negligible (0.01). The relationship of $PM_{0.44}$ and TW at HP locations (Fig. 4.5) was positive with high R^2 value of 0.85 signifying that about 85% of $PM_{0.44}$ concentrations at HP locations could be explained by TW exhaust emissions. The relationship of $PM_{0.44}$ and TW at HU locations was also positive (Fig. 4.6). R^2 value for $PM_{0.44}$ and TW at HU was moderate (0.28). As such, we observed that the $PM_{0.44}$ and TW were strongly related at plain locations in comparison with the steep gradient locations. This indicated change in exhaust emission characteristics of TW with decrease in $PM_{0.44}$ concentrations at uphill locations. The positive and significant ($p < 0.05$) Pearson correlation coefficients (r) between $PM_{0.44}$ and TW at MP and HP locations were positive and strong (0.57 and 0.69 respectively) and positive at MU and HU locations (0.13 and 0.49 respectively) further corroborating the above relationships.

Table 4.17 Relationship of $PM_{0.44}$ with two wheel vehicles		
Equation	R^2	Eq No
$PM_{0.44} (MP) = 0.0297 * TW + 9.93$	0.36	(4.5)
$PM_{0.44} (MU) = 0.0009 * TW + 20.25$	0.01	(4.6)
$PM_{0.44} (HP) = 0.0108 * TW + 11.96$	0.85	(4.7)
$PM_{0.44} (HU) = 0.007 * TW + 17.27$	0.28	(4.8)

The relationship of $PM_{0.44}$ with LV is provided in Table 4.18. The relationship of $PM_{0.44}$ and LV at MP locations (Fig. 4.7) was positive but the R^2 value for $PM_{0.44}$ and LV was almost negligible (0.02). Similarly, relationship of $PM_{0.44}$ and LV at MU locations (Fig. 4.8) was positive with almost negligible (0.02) R^2 value. The relationship of $PM_{0.44}$ and LV at HP and HU locations (Fig. 4.9 and 4.10) was positive with moderate R^2 values (0.45 and 0.19 respectively). The $PM_{0.44}$ was better related at high traffic density locations in comparison with the moderate traffic density locations. The Pearson correlation coefficients (r) between $PM_{0.44}$ and LV at MP and MU locations were positive but weak (0.02 and 0.01 respectively) while positive and moderate (0.45 and 0.19 respectively) at HP and HU locations.

Table 4.18 Relationship of $PM_{0.44}$ with light vehicles		
Equation	R^2	Eq No
$PM_{0.44} (MP) = 0.0014 * LV + 13.73$	0.02	(4.9)
$PM_{0.44} (MU) = 0.0006 * LV + 19.70$	0.01	(4.10)
$PM_{0.44} (HP) = 0.0018 * LV + 14.04$	0.45	(4.11)
$PM_{0.44} (HU) = 0.0015 * LV + 17.56$	0.19	(4.12)

The relationship of $PM_{0.44}$ with HV is provided in Table 4.19. The relationship of $PM_{0.44}$ and HV was positive at the plain locations of MP and HP (Fig. 4.11 and 4.13). R^2 value for $PM_{0.44}$ and HV at MP and HP was moderate (0.57 and 0.42 respectively) indicating that 57% and 42% of $PM_{0.44}$ at MP and HP could be explained by the heavy vehicle emissions at these locations. The relationship of $PM_{0.44}$ and HV was positive at the uphill locations of MU and HU (Fig. 4.12 and

Table 4.19 Relationship of PM _{0.44} with heavy vehicles		
Equation	R ²	Eq No
PM _{0.44} (MP) = 0.0121 * HV + 8.14	0.57	(4.13)
PM _{0.44} (MU) = 0.0063 * HV + 16.45	0.15	(4.14)
PM _{0.44} (HP) = 0.0061 * HV + 17.47	0.42	(4.15)
PM _{0.44} (HU) = - 0.0042 * HV + 28.66	0.07	(4.16)

4.14) but the R² value dropped to 0.15 and 0.07 respectively. This drop suggested that at uphill roads the emission characteristics of HV also got changed demonstrating drop in PM_{0.44} concentrations as was observed for TW. The Pearson correlation coefficients (r) between PM_{0.44} and HV at MP and HP locations were positive (0.69 and 0.65 respectively) and significant (p<0.05) while it was moderately positive at MU locations (0.39) and negative at HU locations (-0.26).

The relationship of PM_{0.44} with ρ_T is provided in Table 4.20. The relationship of PM_{0.44} and ρ_T was positive at MP and HP locations (Fig. 4.15 and 4.17) with R² values of 0.32 and 0.62 respectively. The relationship of PM_{0.44} and ρ_T at MU and HU locations (Fig. 4.16 and 4.18 respectively) was also positive but weak with R² values of 0.04 and 0.19 respectively. These relationships suggested that due to traffic activities the concentration of PM_{0.44} increased at all the locations but it was more prominent at MP and HP locations where about 32% and 62% of PM_{0.44} concentration could be explained by vehicular emissions while only 4% and 19% of PM_{0.44} concentrations could be explained at MU and HU locations. This difference at plain and uphill locations indicated that at high load conditions (steep gradient)

Table 4.20 Relationship of PM _{0.44} with total traffic density		
Equation	R ²	Eq No
PM _{0.44} (MP) = 0.0043 * ρ_T + 6.51	0.32	(4.17)
PM _{0.44} (MU) = 0.0009 * ρ_T + 18.38	0.04	(4.18)
PM _{0.44} (HP) = 0.0016 * ρ_T + 12.61	0.62	(4.19)
PM _{0.44} (HU) = 0.0013 * ρ_T + 15.97	0.19	(4.20)

vehicles emitted comparatively less particles belonging to PM_{0.44} size group. The Pearson correlation coefficients (r) between PM_{0.44} and ρ_T at MP, MU and HU were positive (0.49, 0.21 and 0.43 respectively) and at HP locations it was highly positive (0.80) and significant (p<0.05).

The relationship of PM_{0.88} with TW at MP, MU and HP locations (Fig. 4.3, to 4.5) was positive with insignificant R² values of 0.06, 0.00 and 0.02 respectively. The small R² values were indicative of insignificant PM_{0.88} emissions from TW at these locations. The relationship of PM_{0.88} and TW at HU location (Fig. 4.6) was negative. The Pearson correlation coefficients (r) between PM_{0.88} and TW at MP, MU and HP were positive but weak (0.23, 0.07 and 0.16 respectively) while insignificantly negative at HU locations (-0.00).

The relationship of PM_{0.88} with LV at MP, MU, HP and HU locations (Fig. 4.7 to 4.10) was positive and weak with R² values of 0.00, 0.03, 0.09 and 0.02 respectively. The Pearson correlation coefficients (r) between PM_{0.88} and LV at MP, MU, HP and HU were also positive but weak (0.00, 0.03, 0.09 and 0.02 respectively). The results suggested that contribution of light vehicles in build up of PM_{0.88} in the ambient air at MP, MU, HP and HU locations was insignificant.

The relationship of $PM_{0.88}$ and HV at MP locations (Fig. 4.11) was highly positive with R^2 value of 0.58. The relationship of $PM_{0.88}$ and HV at MU and HP locations (Fig. 4.12 and 4.13 respectively) was positive with moderate R^2 values of 0.47 and 0.29 respectively. Inexplicably, the relationship of $PM_{0.88}$ and HV at HU locations (Fig. 4.14) was positive with small R^2 value of 0.05. The Pearson correlation coefficients (r) between $PM_{0.88}$ and HV at MP and MU locations were highly positive (0.67 and 0.66 respectively) and significant ($p < 0.05$) and strongly positive at HP locations (0.54). Pearson correlation coefficient (r) at HU locations was moderately positive (0.23). The results indicated that relationship of $PM_{0.88}$ with HV gradually became weak from MP to HU locations. In fact, the traffic speed slow down from MP to HU locations. Perhaps, the concentration of $PM_{0.88}$ at these locations had two major sources i.e. one that came directly from vehicular exhausts and the other as resuspended dust. The 2nd factor became prominent at the locations with high traffic speeds thus increasing $PM_{0.88}$ concentrations.

The relationship of $PM_{0.88}$ and ρ_T at MP, MU, HP and HU locations (Fig. 4.15 to 4.18 respectively) was positive with R^2 values of 0.22, 0.12, 0.04 and 0.02 respectively. A gradual decrease in R^2 values was observed which could be due to reasons explained above. The Pearson correlation coefficients (r) between $PM_{0.88}$ and HV at MP, MU, HP and HU locations were moderately positive (0.35, 0.36, 0.21 and 0.15 respectively).

The relationships of $PM_{1.77}$ and $PM_{2.6}$ with TW, LV, HV and ρ_T were provided at Fig. 4.3 to 4.18. The figures indicated weak relationships signifying little contributions from vehicular emissions.

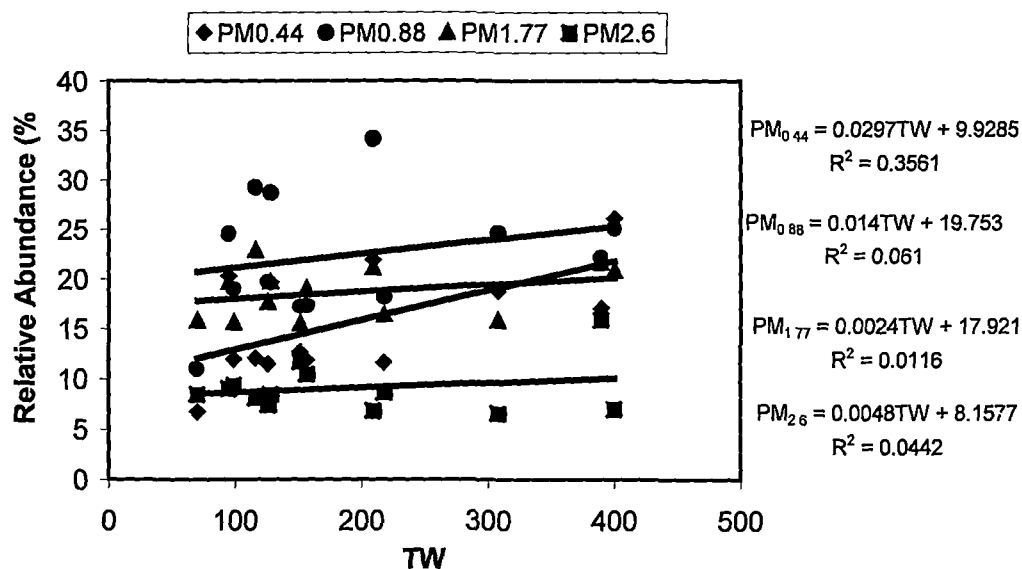


Fig. 4.3 Relationship between PM_{2.5} and TW at MP locations

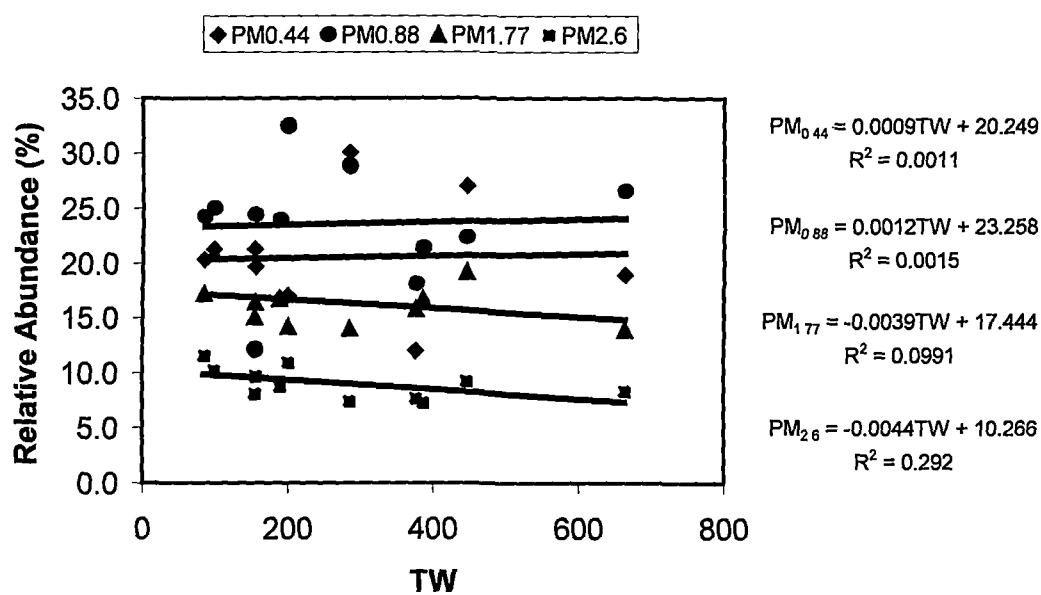


Fig. 4.4 Relationship between PM_{2.5} and TW at MU locations

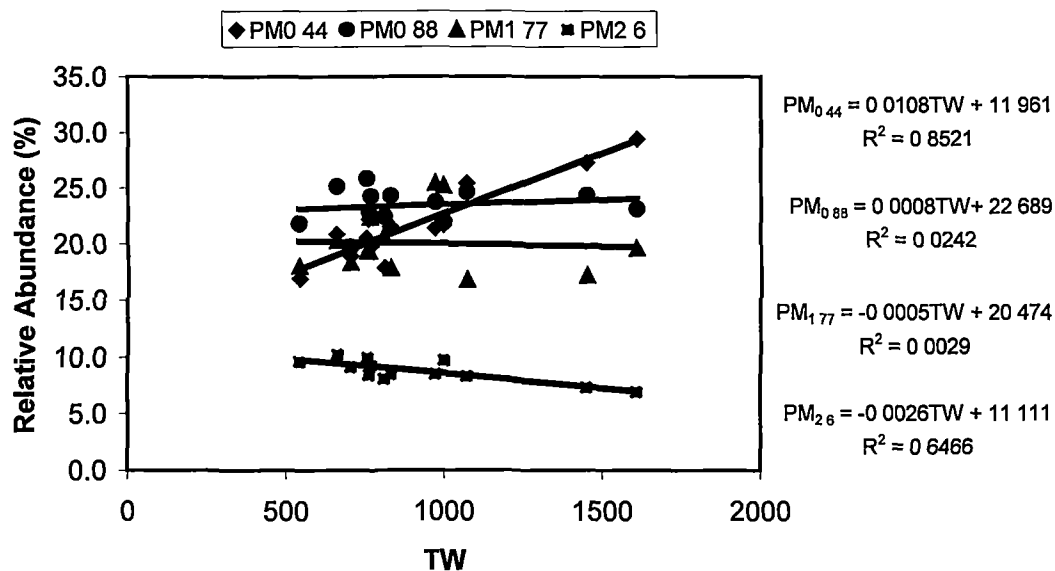


Fig. 4.5 Relationship between PM_{2.5} and TW at HP locations

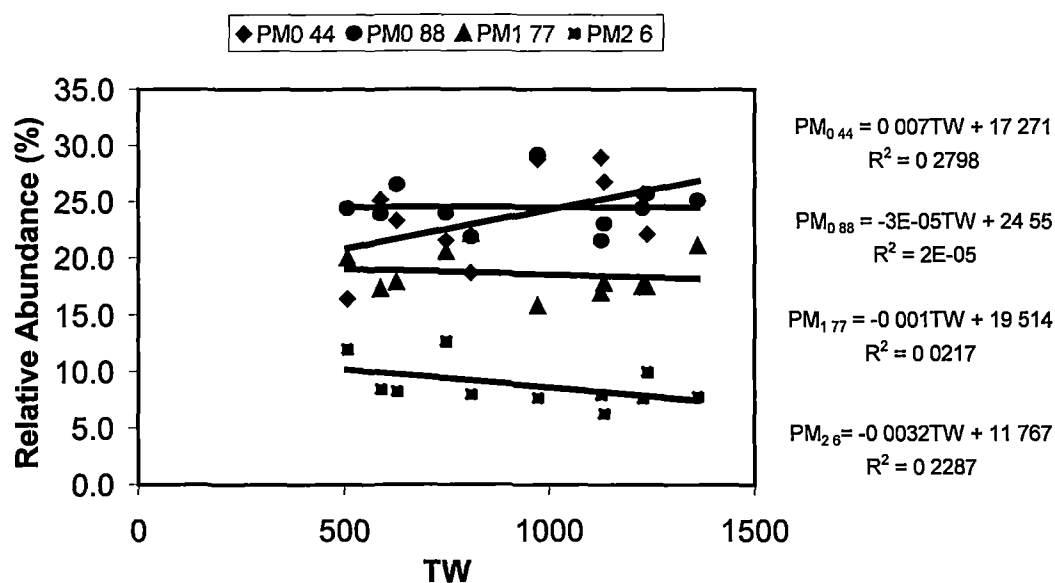


Fig. 4.6 Relationship between PM_{2.5} and TW at HU locations

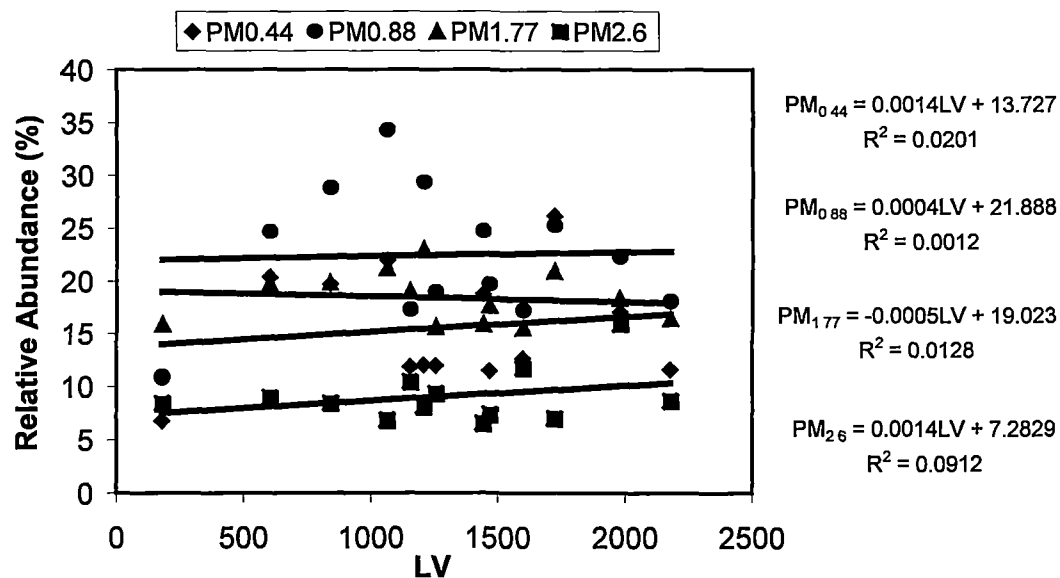


Fig. 4.7 Relationship between PM_{2.5} and LV at MP locations

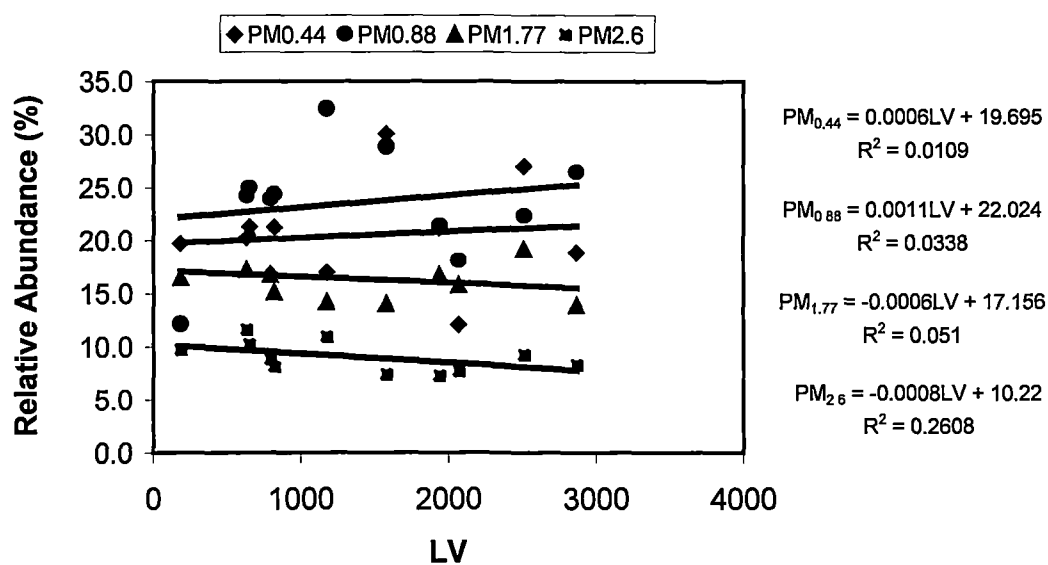


Fig. 4.8 Relationship between PM_{2.5} and LV at MU locations

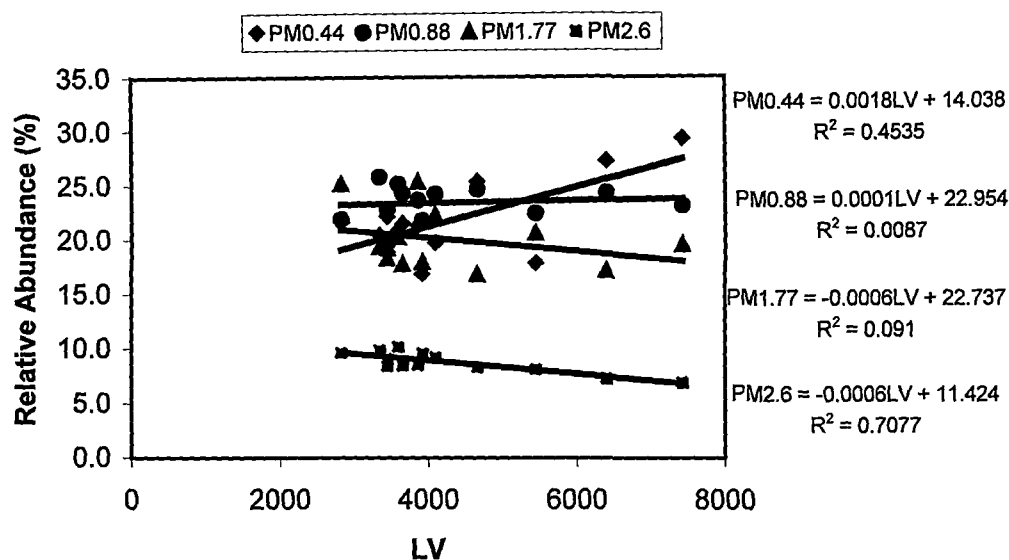


Fig. 4.9 Relationship between PM_{2.5} and LV at HP locations

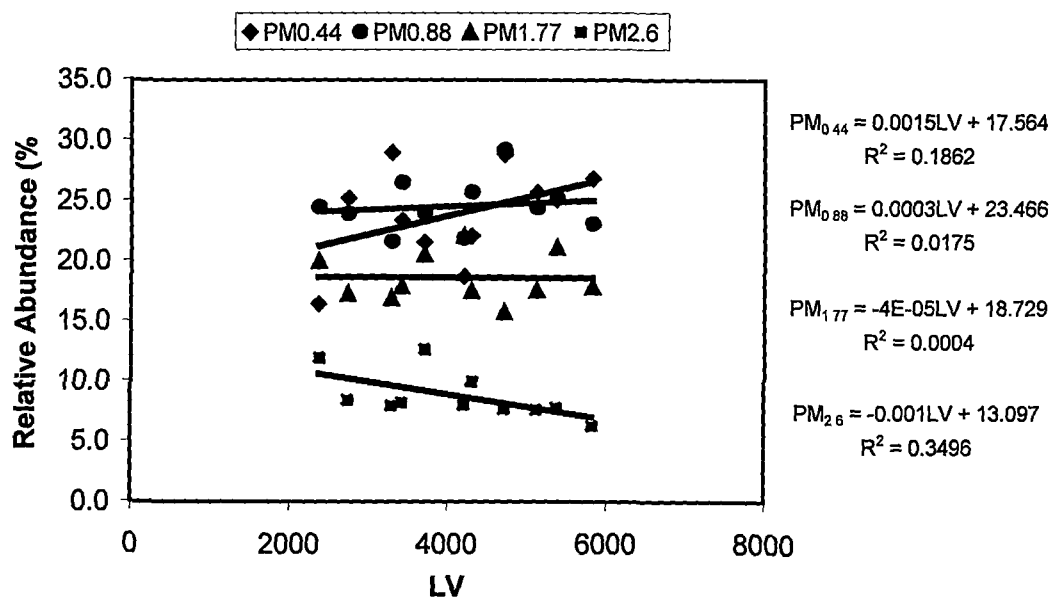


Fig. 4.10 Relationship between PM_{2.5} and LV at HU locations

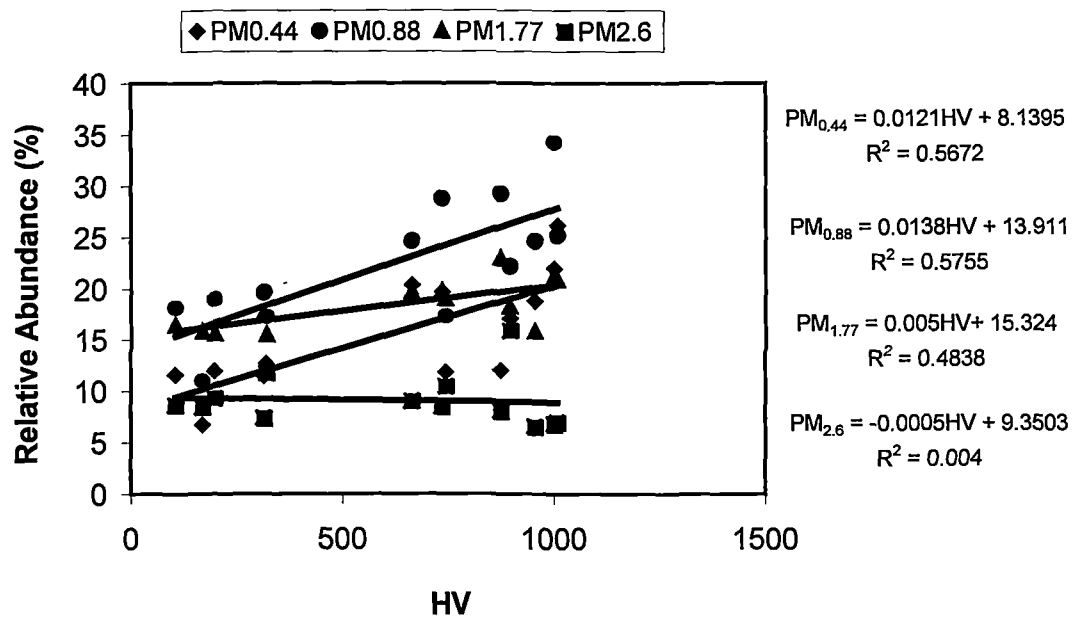


Fig. 4.11 Relationship between PM_{2.5} and HV at MP locations

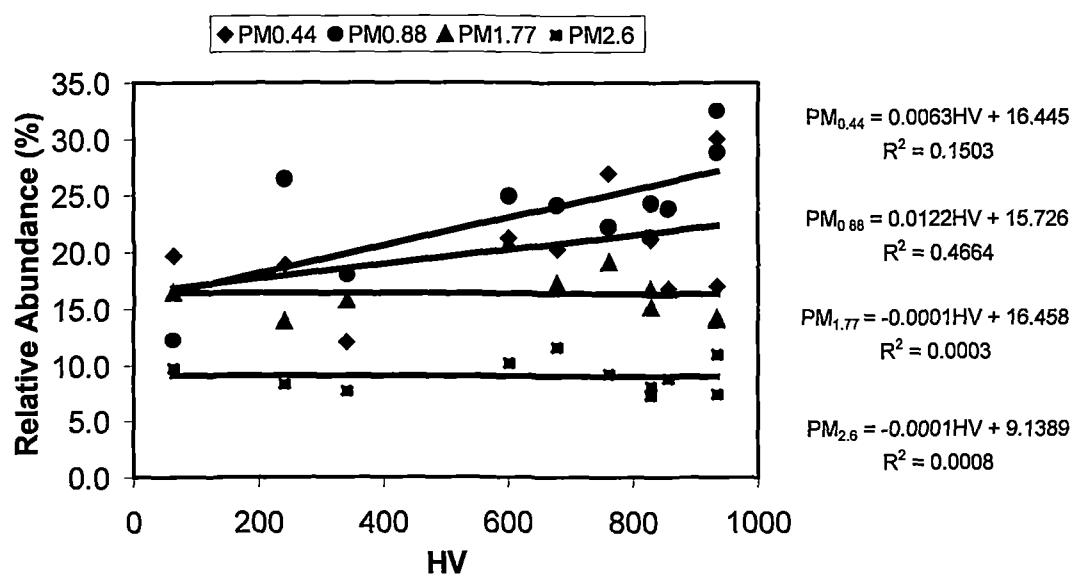


Fig. 4.12 Relationship between PM_{2.5} and HV at MU locations

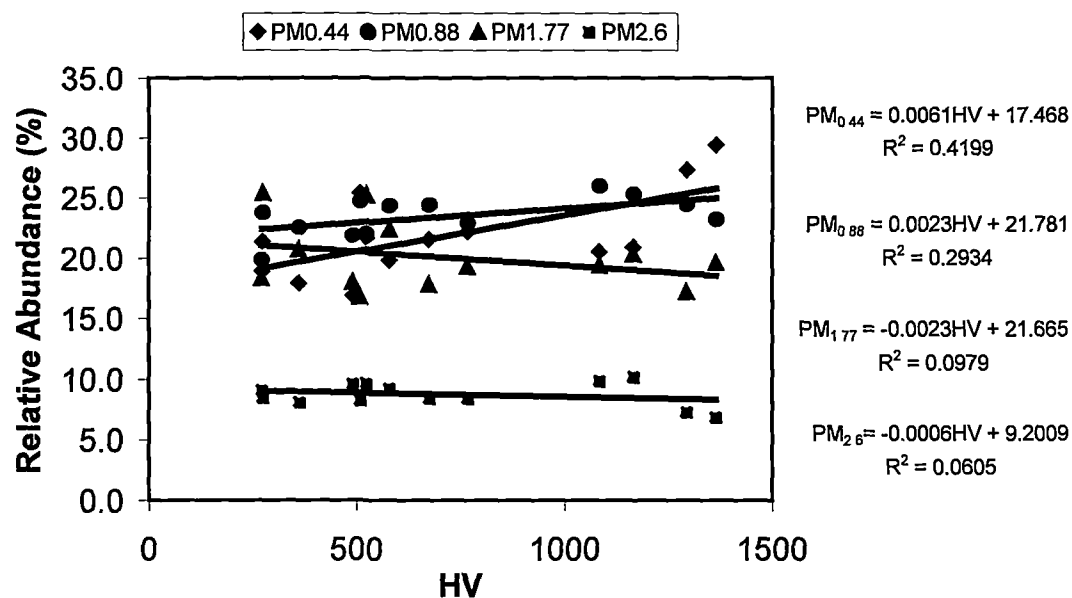


Fig. 4.13 Relationship between PM_{2.5} and HV at HP locations

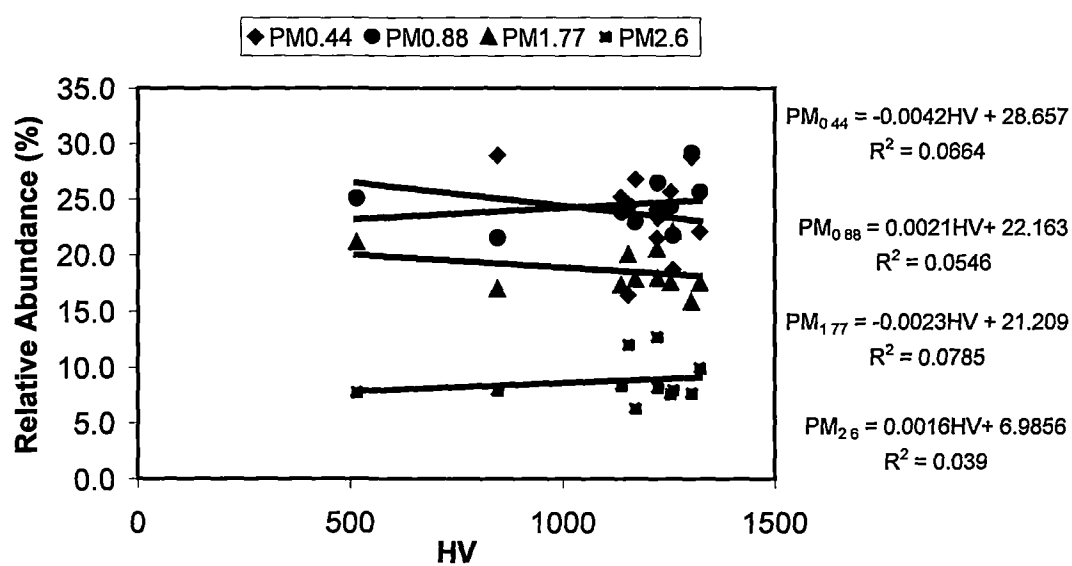


Fig. 4.14 Relationship between PM_{2.5} and HV at HU locations

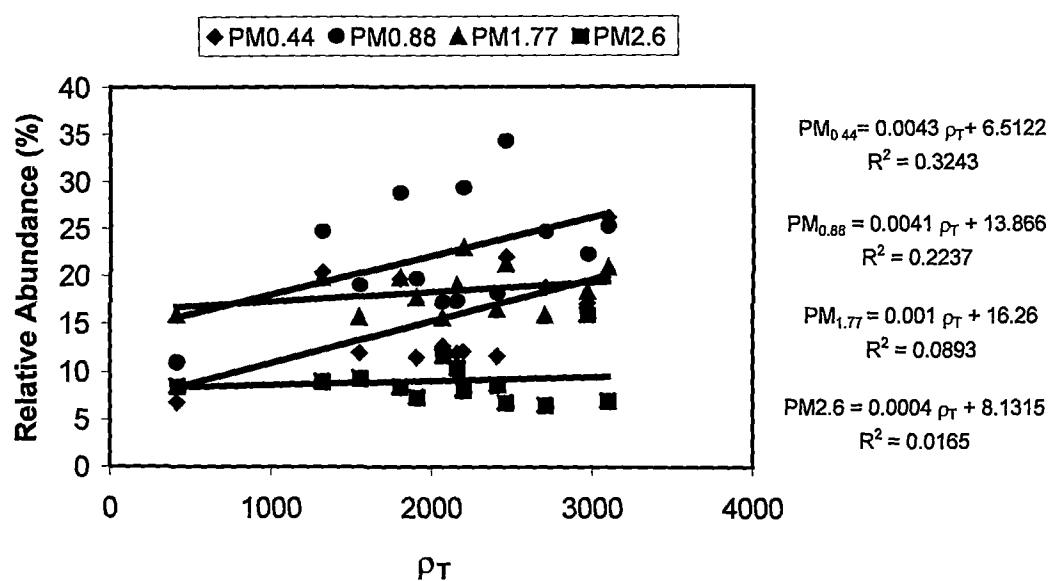


Fig. 4.15 Relationship between $PM_{2.5}$ and ρ_T at MP locations

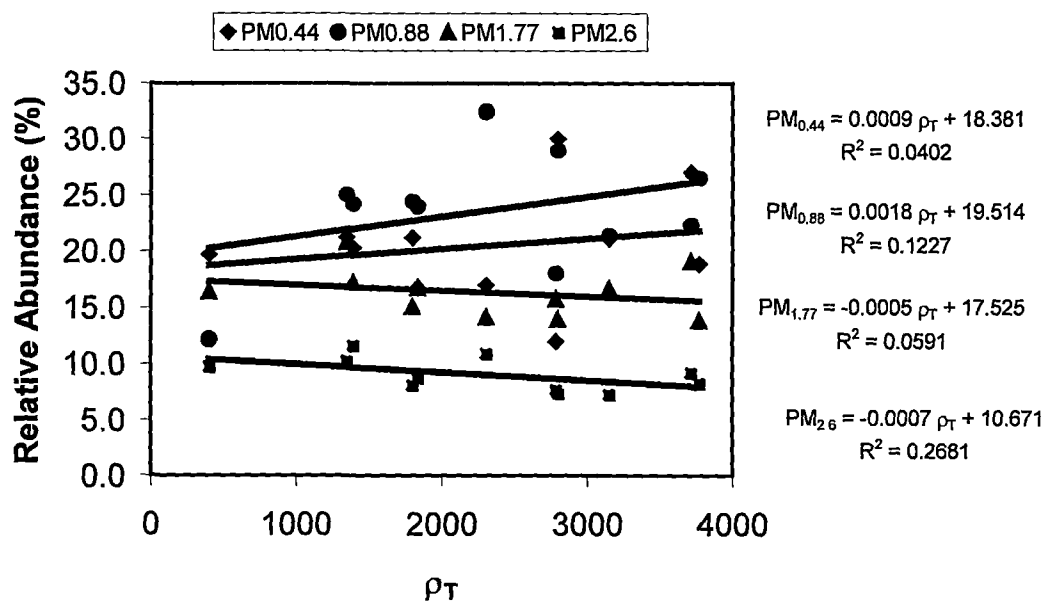


Fig. 4.16 Relationship between $PM_{2.5}$ and ρ_T at MU locations

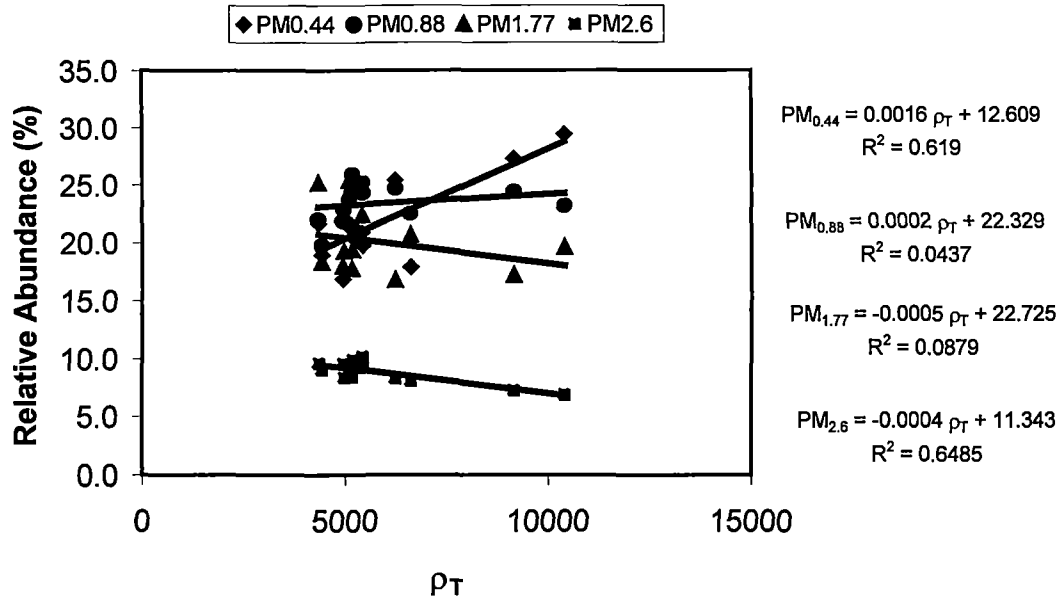


Fig. 4.17 Relationship between $PM_{2.5}$ and ρ_T at HP locations

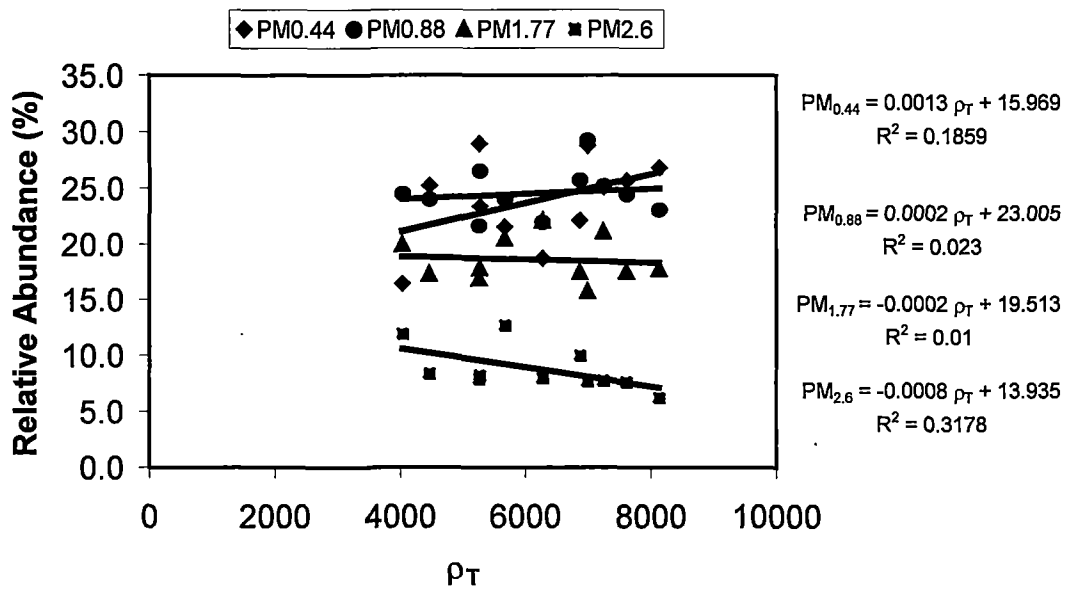


Fig. 4.18 Relationship between $PM_{2.5}$ and ρ_T at HU locations

The relationship of cumulative $PM_{2.5}$ with TW is provided in Table 4.21. The relationship of cumulative $PM_{2.5}$ and TW was positive at MP, HP and HU locations (Fig. 4.19, 4.21 and 4.22) with R^2 values of 0.20, 0.35 and 0.08 respectively while it had been negative at MU locations (Fig. 4.20) with R^2 value of 0.02. The relationship suggested that about 35% of cumulative $PM_{2.5}$ concentrations at HP locations could be explained by TW emissions. The Pearson correlation coefficient (r) between cumulative $PM_{2.5}$ and TW was positive at MP, HP and HU locations (0.42, 0.59 and 0.28 respectively) and significant ($p < 0.05$) at HP while it was negative at MU locations (-0.52).

Table 4.21 Relationship of cumulative $PM_{2.5}$ with two wheel vehicles		
Equation	R^2	Eq No
Cumulative $PM_{2.5}$ (MP) = $0.049 * TW + 55.85$	0.20	(4.21)
Cumulative $PM_{2.5}$ (MU) = $-0.0063 * TW + 71.24$	0.02	(4.22)
Cumulative $PM_{2.5}$ (HP) = $0.0085 * TW + 66.24$	0.35	(4.23)
Cumulative $PM_{2.5}$ (HU) = $0.0028 * TW + 73.15$	0.08	(4.24)

The relationship of cumulative $PM_{2.5}$ with LV is provided in Table 4.22. The relationship of cumulative $PM_{2.5}$ and LV was positive at MP, MU, HP and HU locations (Fig. 4.23 to 4.26) but weak with R^2 values of 0.01, 0.00, 0.04 and 0.07 respectively. The Pearson correlation coefficients (r) between cumulative $PM_{2.5}$ were positive but negligible at MP and MU locations (0.11 and 0.03 respectively) and were moderately positive at HP and HU locations (0.21 and 0.26 respectively).

Table 4.22 Relationship of cumulative PM_{2.5} with light vehicles		
Equation	R²	Eq No
Cumulative PM _{2.5} (MP) = 0.0027 * LV + 61.90	0.01	(4.25)
Cumulative PM _{2.5} (MU) = 0.0003 * LV + 69.11	0.00	(4.26)
Cumulative PM _{2.5} (HP) = 0.0007 * LV + 71.17	0.04	(4.27)
Cumulative PM _{2.5} (HU) = 0.0007 * LV + 72.88	0.07	(4.28)

The relationship of cumulative PM_{2.5} with HV is provided in Table 4.23. The relationship of HV at MP, MU and HP locations (Fig. 4.27 to 4.29) was positive with R² values of 0.71, 0.43 and 0.22 respectively. The association suggested that 71%, 43% and 22% of cumulative PM_{2.5} concentrations at MP, MU and HP locations respectively could be explained by HV emissions. The relationship of cumulative PM_{2.5} and HV was negative at HU locations (Fig. 4.30) with R² value of 0.05. It may be observed that the association of cumulative PM_{2.5} and HV

Table 4.23 Relationship of cumulative PM_{2.5} with heavy vehicles		
Equation	R²	Eq No
Cumulative PM _{2.5} (MP) = 0.0301 * HV + 46.805	0.71	(4.29)
Cumulative PM _{2.5} (MU) = 0.0183* HV + 57.73	0.43	(4.30)
Cumulative PM _{2.5} (HP) = 0.0055 * HV + 70.12	0.22	(4.31)
Cumulative PM _{2.5} (HU) = -0.0028 * HV + 78.96	0.05	(4.32)

gradually became weak from MP to HU locations. As we discussed in the sub-sections above, that the particle size distributions characteristics of heavy vehicles changed at uphill conditions with bias towards emission of bigger particles and, as

such, we observed the gradual weak associations of cumulative $PM_{2.5}$ with HV. The Pearson correlation coefficient (r) between cumulative $PM_{2.5}$ and HV was highly positive and significant ($p < 0.05$) at MP and MU locations (0.77 and 0.66 respectively) while moderately positive at HP locations (0.48). The Pearson correlation coefficient (r) between cumulative $PM_{2.5}$ and HV was negative at HU locations (-0.23).

The relationship of cumulative $PM_{2.5}$ with ρ_T is provided in Table 4.24. The relationship of cumulative $PM_{2.5}$ and ρ_T was positive at MP, MU, HP and HU locations (Fig. 4.31 to 4.34) with R^2 values of 0.33, 0.03, 0.12 and 0.06 respectively. We observed that the relationship was stronger at MP and HP locations while comparatively weak at MU and HU locations. It appeared from these results that the high vehicle speeds as prevailed at MP locations facilitated uplifting of fine dust particles from the roads thus providing stronger cumulative $PM_{2.5}$ and ρ_T relationship. The Pearson correlation coefficient (r) between cumulative $PM_{2.5}$ and ρ_T was moderately positive at MP and HP locations (0.49 and 0.36 respectively) and positive but weak at MU and HU locations (0.19 and 0.24 respectively).

Table 4.24 Relationship of cumulative $PM_{2.5}$ with total traffic density		
Equation	R^2	Eq No
Cumulative $PM_{2.5}$ (MP) = $0.0098 * \rho_T + 44.92$	0.33	(4.33)
Cumulative $PM_{2.5}$ (MU) = $0.0015 * \rho_T + 66.11$	0.03	(4.34)
Cumulative $PM_{2.5}$ (HP) = $0.0008 * \rho_T + 69.03$	0.12	(4.35)
Cumulative $PM_{2.5}$ (HU) = $0.0005 * \rho_T + 72.45$	0.06	(4.36)

Our findings of relationships for cumulative $PM_{2.5}$ and total traffic density were quite in accordance with those of Lam *et al.* (1999), who observed the following relationship between $PM_{2.5}$ and total traffic density in Hong Kong:

$$PM_{2.5} = 0.0007 * \rho_T + 95.26 \quad (\text{Eq. No 4.37})$$

The R^2 value obtained by Lam *et al.* (1999) for above relationship was 0.12. Our average R^2 value for the MP, MU, HP and HU locations had been 0.13, which was similar with the findings of the Lam *et al.* (1999).

The relationship of PM_5 with TW was negative at MP locations (Fig. 4.19) with R^2 value of 0.21 while it was positive at MU, HP and HU locations (Fig. 4.20, 4.21 and 4.22) with R^2 values of 0.17, 0.16 and 0.00 respectively. The Pearson correlation coefficient (r) between PM_5 and TW was negative at MP location (-0.44) and moderately positive at MU and HP locations (0.42 and 0.40 respectively) while it had positive but weak relationship at HU locations (0.06).

The relationship of PM_5 and LV was negative at MP locations (Fig. 4.23) with R^2 value of 0.03 while it was positive at MU, HP and HU locations (Fig. 4.24 to 4.26) with R^2 values of 0.06, 0.40 and 0.00 respectively. The Pearson correlation coefficient (r) between PM_5 and LV was negative at MP locations (-0.15) and moderately positive at MU locations (0.25) and positive but weak at HU locations (0.02). The relationship between PM_5 and LV was highly positive (0.65) and significant ($p < 0.05$) at HP locations.

The relationship of PM_5 with HV was negative at MP and MU locations (Fig. 4.27 and 4.28) with R^2 values of 0.27 and 0.26 respectively while it was

positive at HP and HU locations (Fig. 4.29 and 4.30) with R^2 values of 0.33 and 0.07 respectively. The Pearson correlation coefficient (r) between PM_5 and HV was negative at MP and MU locations (-0.41 and -0.51 respectively) and highly positive (0.58) and significant ($p < 0.05$) at HP locations and moderately positive at HU locations (0.27).

The relationship of PM_5 with ρ_T was negative at MP locations (Fig. 4.31) with R^2 value of 0.19 while it was positive at MU, HP and HU locations (Fig. 4.32 to 4.34) with R^2 values of 0.02, 0.42 and 0.01 respectively. The Pearson correlation coefficient (r) between PM_5 and ρ_T was negative at MP locations (-0.35), positive but weak at MU locations (0.13), highly positive and significant ($p < 0.05$) at HP locations and positive but weak at HU locations (0.08).

As pointed out above, the PM_5 showed negative associations with TW, LV, HV and ρ_T at MP locations (HV showed negative association at MU also). It seemed likely that considerably higher concentration of finer particles was due to comparatively high exhaust emissions at MU, HP and HU locations (because of the accelerated engine speeds at MU and HU (steep gradients) and high traffic density at HP and HU locations that helped faster coagulation of fine particles to bigger size groups. The generally high humid conditions at these locations appeared to have further facilitated the phenomenon.

The relationship of PM_{10} with TW was negative at MP, MU, HP and HU locations (Fig. 4.19 to 4.22) with R^2 values of 0.18, 0.01, 0.66 and 0.47 respectively. The Pearson correlation coefficient (r) between PM_{10} and TW was also negative at MP and MU locations (-0.40, and -0.07 respectively) and negative and significant

($p < 0.05$) at HP and HU locations (0.81 and 0.68 respectively). The relationship of PM_{10} with LV was also negative at MP, MU, HP and HU locations (Fig. 4.23 to 4.26) with R^2 values of 0.01, 0.07, 0.30 and 0.55 respectively. The Pearson correlation coefficient (r) between PM_{10} and LV was also negative at MP, MU and HP locations (-0.11, -0.25 and -0.55 respectively) and negative and significant ($p < 0.05$) at HP location (-0.74).

The relationship of PM_{10} with HV was negative at MP, MU, HP and HU locations (Fig. 4.27 to 4.30) with R^2 values of 0.75, 0.47, 0.48 and 0.02 respectively. The Pearson correlation coefficient (r) between PM_{10} and HV was also negative and significant ($p < 0.05$) at MP, MU and HP locations (-0.80, -0.69 and -0.70 respectively) and negative at HU location (-0.14).

The relationship of PM_{10} with ρ_T was negative at MP, MU, HP and HU locations (Fig. 4.31 to 4.34) with R^2 values of 0.34, 0.17, 0.47 and 0.55 respectively. The Pearson correlation coefficient (r) between PM_{10} and ρ_T was negative at MP and MU locations (-0.50 and -0.41 respectively) and negative and significant ($p < 0.05$) at HP and HU locations (-0.69 and -0.74 respectively).

The above results implied that increase in fine particle concentrations created sudden dilution effect on PM_{10} concentrations thus giving negative relationships with TW, LV, HV and ρ_T .

Lam *et al.* (1999) had observed the following relationship between PM_{10} and total traffic density ($R^2 = 0.05$) contrary to our findings that showed negative association:

$$PM_{10} = 0.0006 * \rho_T + 134.68$$

(Eq. No 4.38)

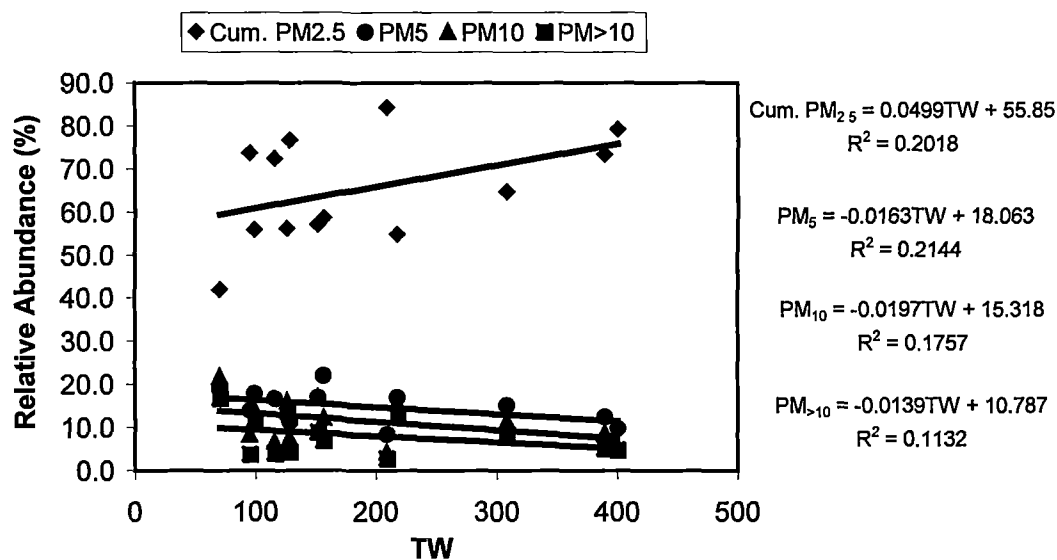


Fig. 4.19 Relationship between solid particles and TW at MP locations

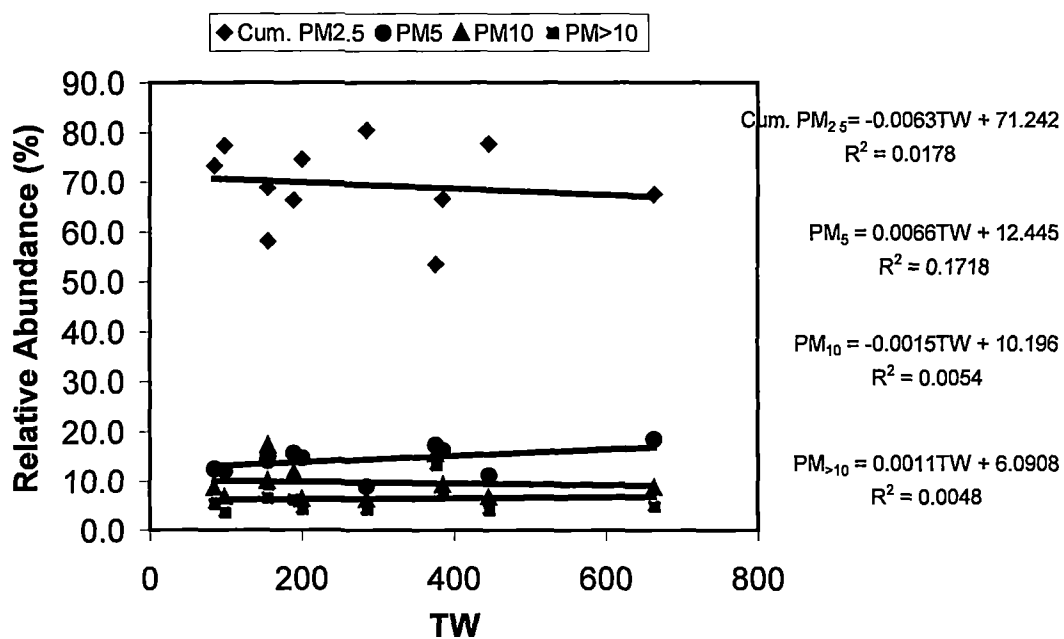


Fig. 4.20 Relationship between solid particles and TW at MU locations

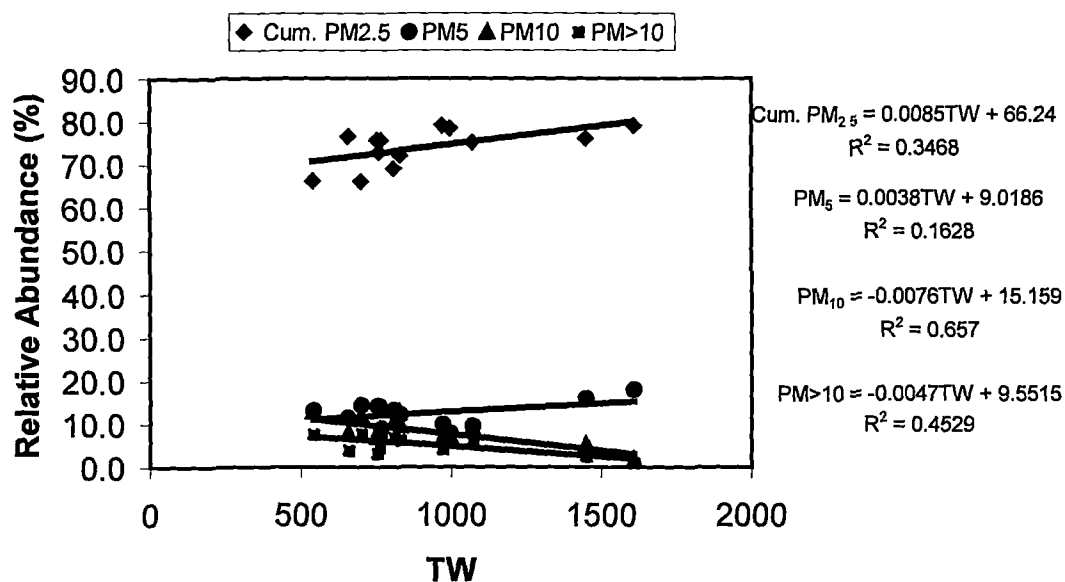


Fig. 4.21 Relationship between solid particles and TW at HP locations

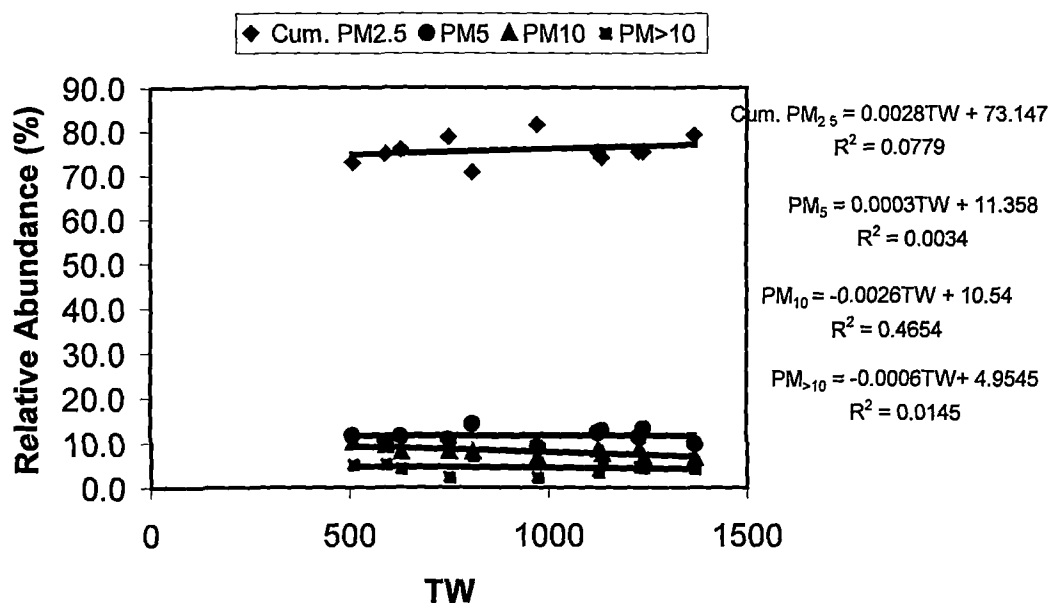


Fig. 4.22 Relationship between solid particles and TW at HU locations

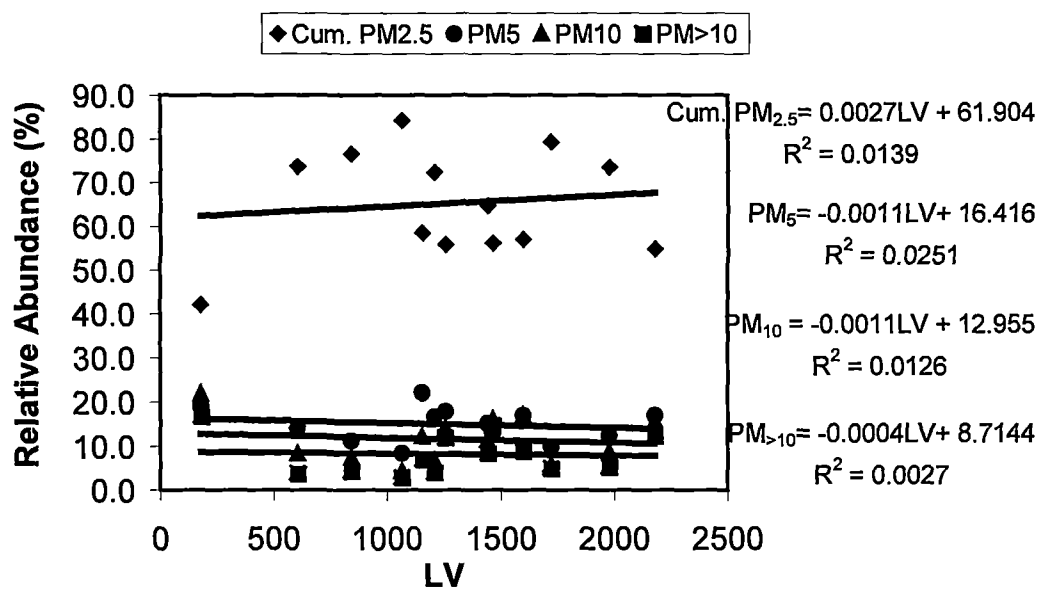


Fig. 4.23 Relationship between solid particles and LV at MP locations

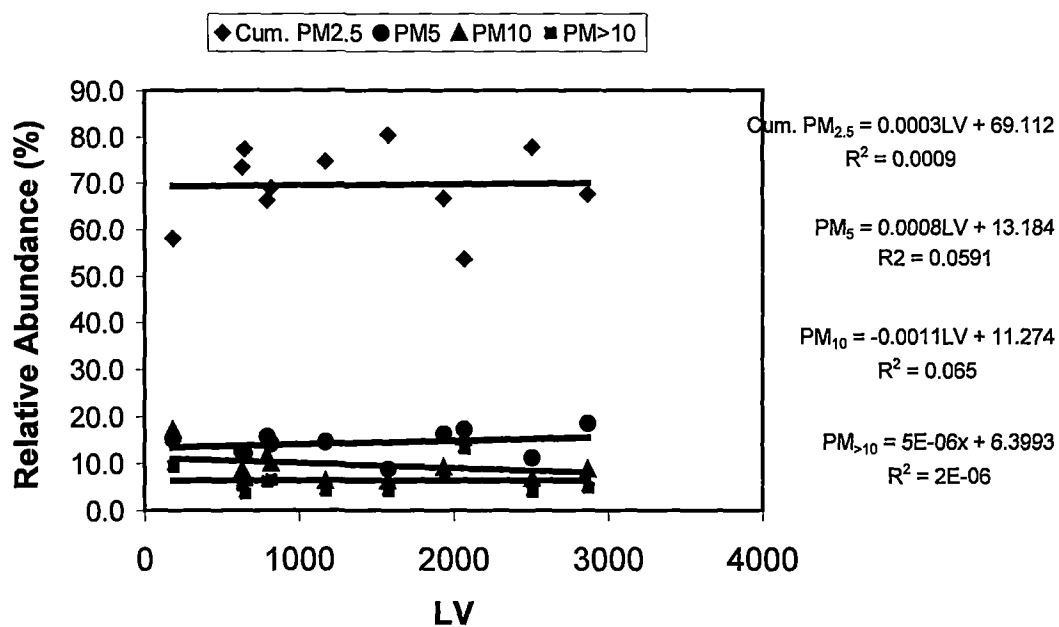


Fig. 4.24 Relationship between solid particles and LV at MU locations

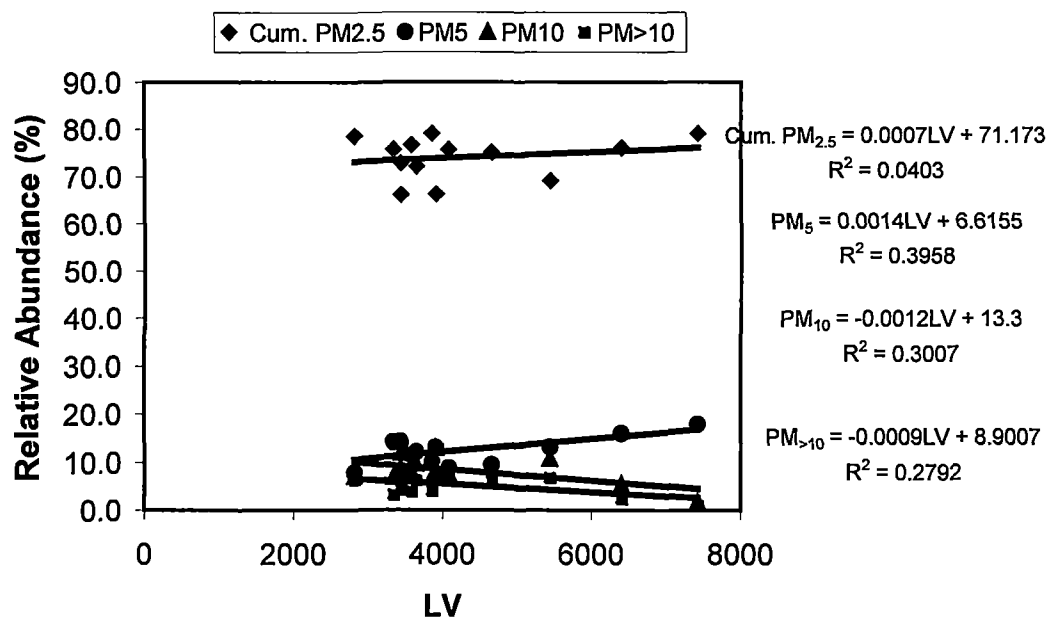


Fig. 4.25 Relationship between solid particles and LV at HP locations

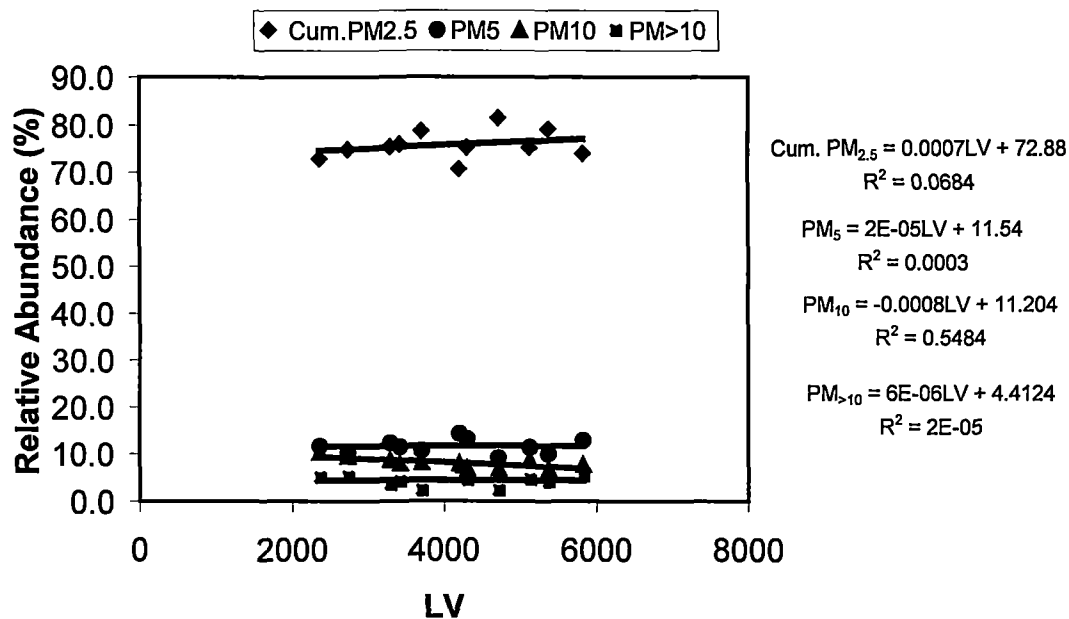


Fig. 4.26 Relationship between solid particles and LV at HU locations

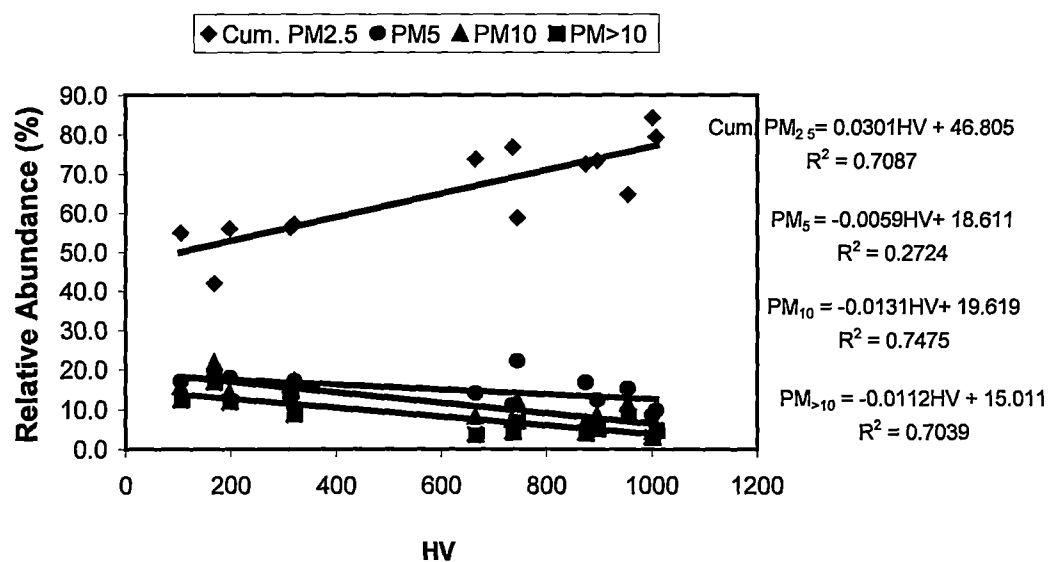


Fig. 4.27 Relationship between solid particles and HV at MP locations

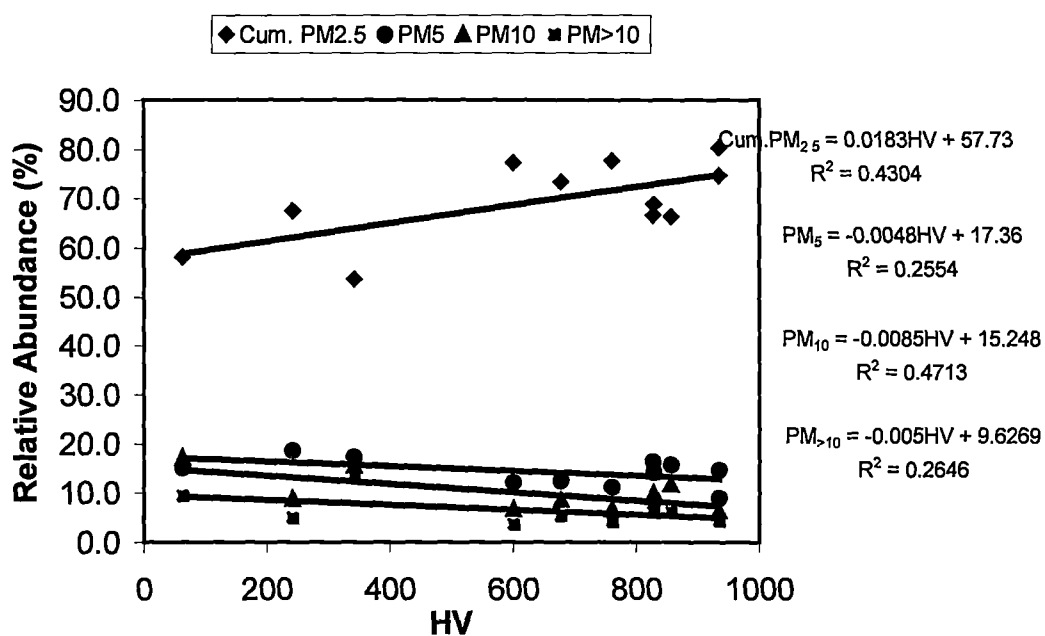


Fig. 4.28 Relationship between solid particles and HV at MU locations

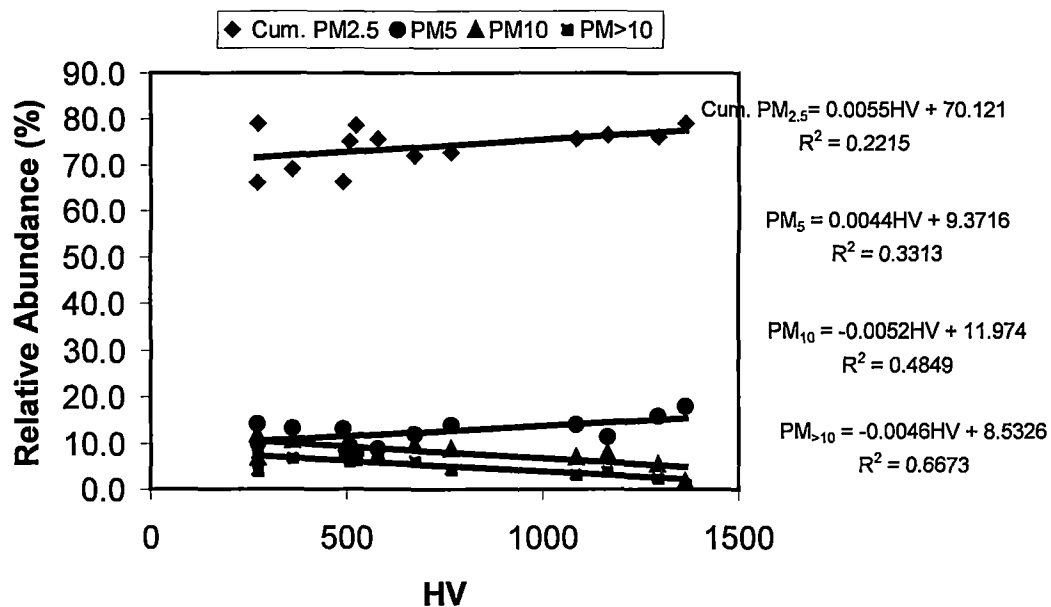


Fig. 4.29 Relationship between solid particles and HV at HP locations

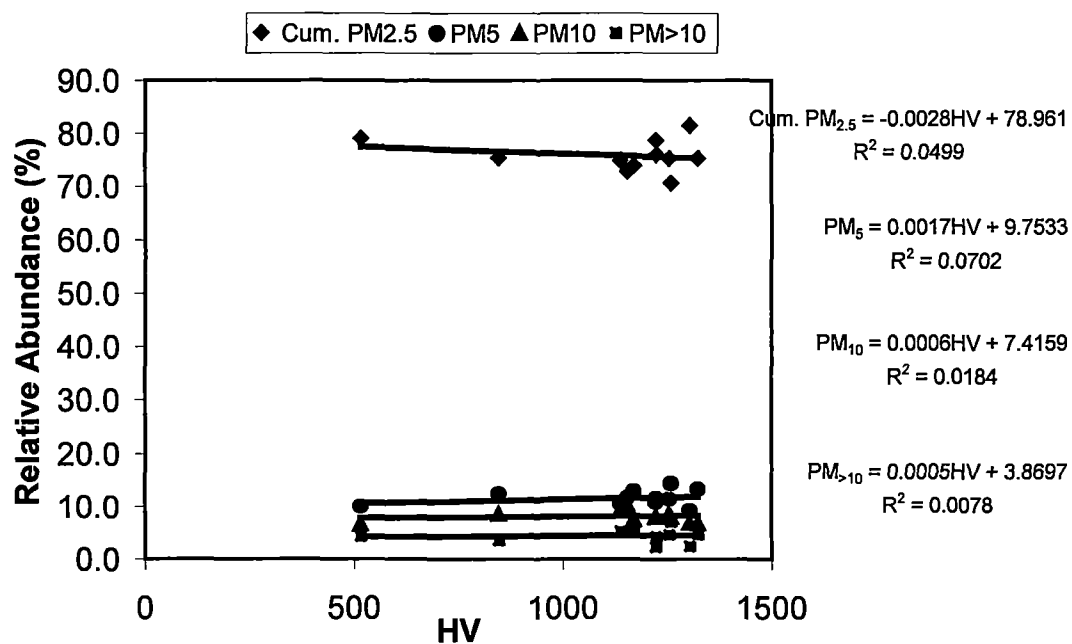


Fig. 4.30 Relationship between solid particles and HV at HU locations

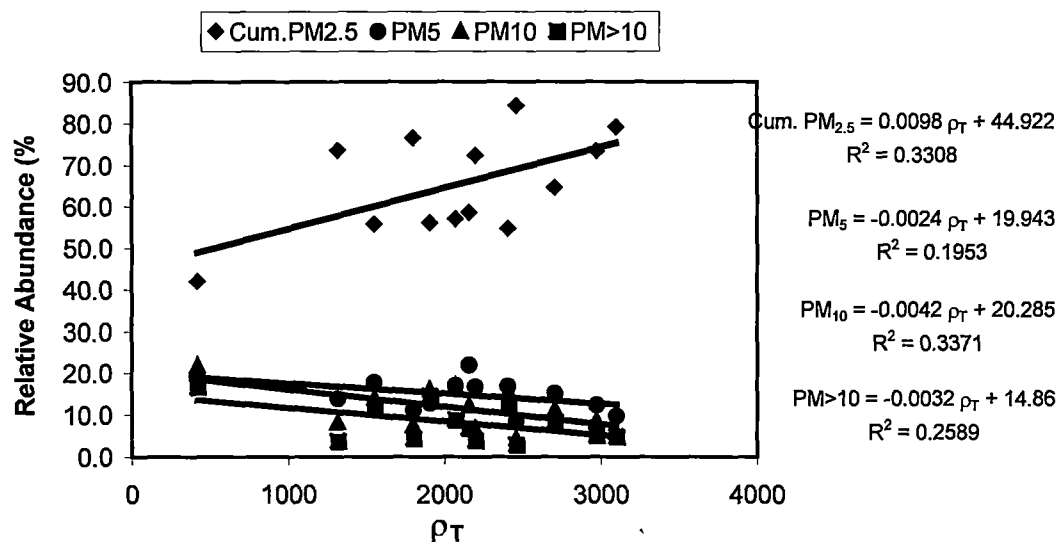


Fig. 4.31 Relationship between solid particles and ρ_T at MP locations

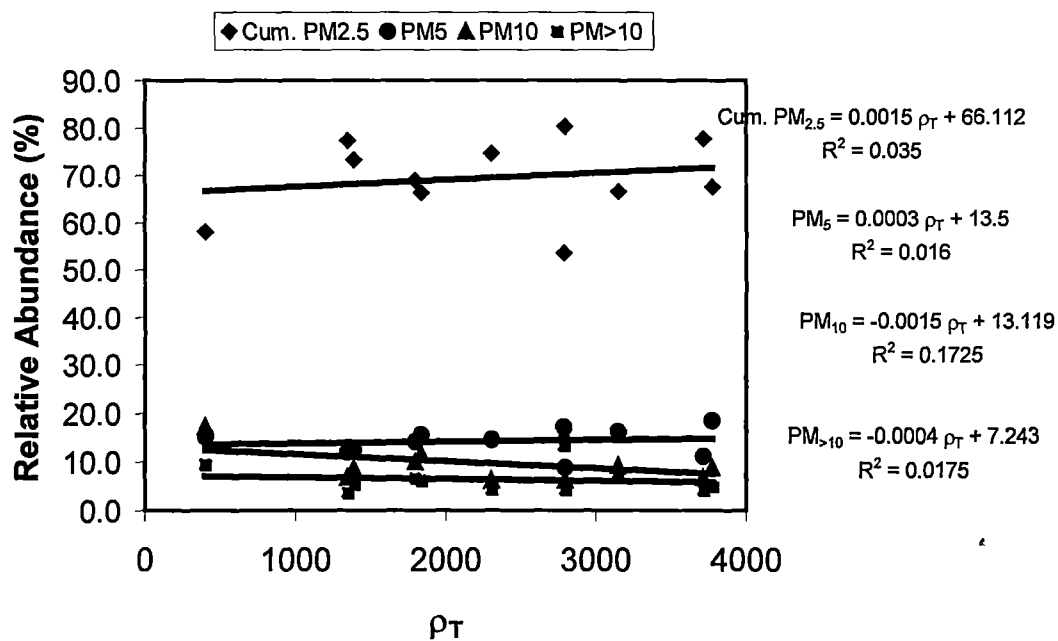


Fig. 4.32 Relationship between solid particles and ρ_T at MU locations

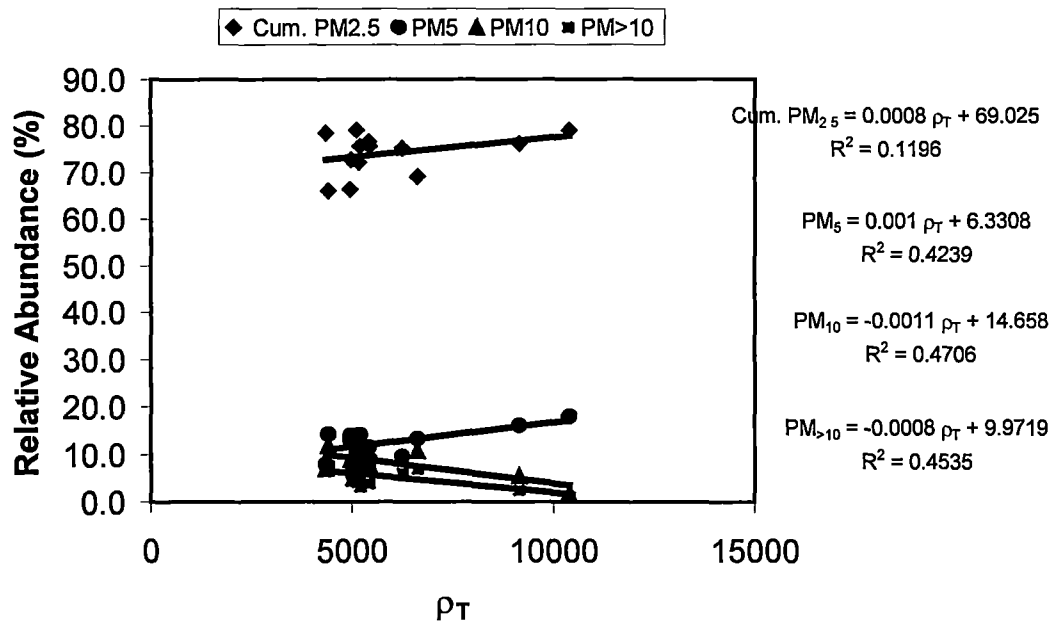


Fig. 4.33 Relationship between solid particles and ρ_T at HP locations

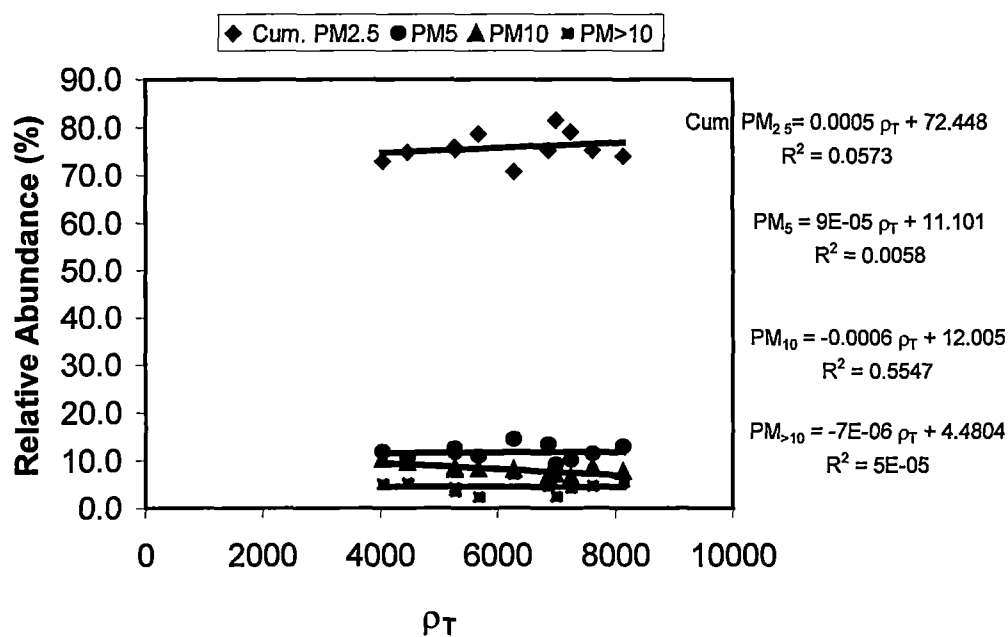


Fig. 4.34 Relationship between solid particles and ρ_T at HU locations

We measured one additional size group of PM_5 between $PM_{2.5}$ and PM_{10} size and the same was not evaluated by Lam *et al.* (1999). As such, the relationship they obtained would have been for the particles belonging to the size range of $PM_{2.5}$ - PM_{10} and in our case it belonged to PM_5 - PM_{10} size range. In fact, if we consider the relationship of PM_5 with traffic density, we found that it was moderately positive at HP location. The average R^2 value of PM_5 with traffic density was about 0.15. The relationship of $PM_{>10}$ with TW, LV, HV and ρ_T was normally negative and not very strong (Fig. 4.19 to 4.34).

From the overall particle size distributions and traffic density relationships results, it became clear that these relationships were highly site dependent. Brook *et al.* (1997) had also made similar observations for some urban and rural locations of Canada.

4.5.4 Source apportionment of solid particles using factor analysis technique

The particle size distributions obtained for $PM_{0.44}$, $PM_{0.88}$, $PM_{1.77}$, $PM_{2.6}$, PM_5 , PM_{10} and $PM_{>10}$ at MP, MU, HP and HU locations were subjected to factor analysis using Principal Component Analysis (PCA) with Varimax Rotation method to obtain principal components or factors for source apportionment of the particulates. The method had been widely used by several workers effectively. Usually, the factors having Eigen value cut off at unity were considered for identification of the possible sources of pollutants. One of the reasons might be that some of the software (SPSS/PC+) had Eigen values cut off at unity by default. Such factors, if could define % variance of about 75%, were considered adequate. We

considered 5-factor approach for performing the PCA with Varimax rotation irrespective of their Eigen value to understand their slightest possible contribution since the software used (Statistica 4.5) had the facility to perform such exercise. The following 5-factors were considered:

Factor 1-Vehicular emissions

Factor 2-Resuspended dust due to vehicular motions

Factor 3-Gas-particle conversion reactions and coagulation

Factor 4-Other fugitive sources like domestic fuel burning and

Factor 5-Biogenic and other wind blown particles of natural occurrence

Factor loadings, Eigen values and % total variance had explained the strength of the sources that were virtually represented by these factors. This had been further established by communality of the common factors.

The factor loadings, Eigen values, % total variance and communality of factors for solid particles at MP locations is provided in Table 4.25. 2 factors were observed with Eigen values above unity. Factor 1 could be identified as vehicular emissions as it had high factor loadings for $PM_{0.44}$ and $PM_{0.88}$ and significantly higher loadings for $PM_{1.77}$. Factor 2 could be the resuspended dust uplifted due to vehicular motions as it had moderate factor loadings for $PM_{0.44}$, $PM_{0.88}$ and $PM_{1.77}$. About 83% variance of solid particles at MP locations was accounted by these 2 factors alone. Factor 3 could be the gas-particle conversion factor due to high loadings of $PM_{0.44}$ and $PM_{0.88}$ and moderate loadings of $PM_{1.77}$ while factor 4 could

be the domestic fuel burning and factor 5 appeared to be biogenic source as it had loadings for $PM_{2.6}$, PM_5 , PM_{10} and $PM_{>10}$. These 5 factors together explained

Table 4.25 Factor loadings for solid particles at MP locations

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
$PM_{0.44}$	0.26	0.12	0.54	0.79*	-0.07	0.99
$PM_{0.88}$	0.57	0.21	0.44	0.35	-0.55	0.99
$PM_{1.77}$	0.96*	0.12	0.18	0.17	-0.06	0.99
$PM_{2.6}$	-0.06	-0.99	-0.09	-0.02	0.03	0.99
PM_5	-0.22	-0.09	-0.91	-0.28	0.13	0.99
PM_{10}	-0.67	-0.01	-0.33	-0.55	0.33	0.98
$PM_{>10}$	-0.64	0.17	-0.15	-0.62	0.35	0.98
Eigen Values	4.70	1.09	0.71	0.23	0.17	
%Total Variance	67.16	15.67	10.13	4.13	2.39	
% Cumulative Variance	67.16	82.83	92.96	97.09	99.48	

almost 100% of solid particle concentrations at MP locations. The communality of these factors had almost been near unity that further established that the 5-factor model could be satisfactorily applied at MP locations.

At MU locations (Table 4.26), 3 factors were obtained with Eigen values above unity. Factor 1 could be identified as vehicular emissions as it had moderate factor loadings for $PM_{0.44}$ and $PM_{2.6}$ and very high for $PM_{0.88}$. The heavy loadings of $PM_{0.88}$ for Factor 1 were in accordance with our earlier observations that the emission characteristics of vehicles changed at steep gradient conditions with bias towards emission of bigger particles. Again, factor 2 could be the resuspended dust.

It had moderate loadings for $PM_{0.44}$ and $PM_{2.6}$ and significantly higher values for $PM_{1.77}$. The resuspension of road dust depended on the vehicle weight and load conditions. At high load conditions as prevailed at MU locations, even bigger particles could be resuspended. This explained the higher loadings for $PM_{1.77}$. Factor

Table 4.26 Factor loadings for solid particles at MU locations

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
$PM_{0.44}$	0.26	0.04	0.88*	0.19	0.33	0.99
$PM_{0.88}$	0.95*	-0.28	0.05	-0.07	-0.12	0.99
$PM_{1.77}$	-0.07	0.97*	0.14	-0.17	0.01	0.99
$PM_{2.63}$	0.13	0.16	-0.01	-0.97	0.00	0.99
PM_5	-0.23	-0.17	-0.92	0.15	0.17	0.99
PM_{10}	-0.91	-0.09	-0.34	0.04	-0.06	0.97
$PM_{>10}$	-0.79	-0.10	-0.38	0.26	-0.37	0.98
Eigen Values	3.50	1.49	1.23	0.49	0.23	
% Total Variance	49.98	21.32	17.63	7.02	3.28	
% Cumulative Variance	49.98	71.30	88.94	95.97	99.24	

3 could be gas-particle conversion factor as it was significantly loaded for $PM_{0.44}$ and moderately for $PM_{0.88}$ and $PM_{1.77}$. These three factors together accounted for about 89% variance for solid particles at MU locations. Factor 4 appeared to be biogenic source as it had loadings for PM_5 , PM_{10} and $PM_{>10}$. Factor 5 could probably be the domestic fuel burning as it had moderate loadings for $PM_{0.44}$. These 5 factors together explained 99% of solid particle concentrations at MU locations. The communality of these factors at MU locations was also almost unity that further established that the 5-factor model could be satisfactorily applied for MU location.

At HP locations (Table 4.27), 2 factors were obtained with Eigen values above unity and the 3rd factor with Eigen values almost unity. Factor1 could be identified as vehicular emissions as it had significantly higher factor $PM_{0.44}$ for Factor 1 were expected as HP locations had high traffic density. Yet again, factor 2 could be the resuspended dust. It had moderate loadings for $PM_{0.44}$, $PM_{0.88}$, PM_5 , PM_{10} and $PM_{>10}$. Unlike the observations made for MP locations, the moderate loadings for PM_5 and PM_{10} at HP locations were expected due to high traffic density. Factor 3 could be gas-particle conversion factor as it was loaded for loadings for

Table 4.27 Factor loadings for solid particles at HP locations

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
$PM_{0.44}$	0.86*	0.22	0.13	-0.43	-0.05	0.99
$PM_{0.88}$	0.26	0.06	0.96*	0.05	0.05	0.99
$PM_{1.77}$	0.07	-0.97*	-0.06	0.13	0.20	0.99
$PM_{2.6}$	-0.33	-0.14	0.07	0.90*	0.21	0.99
PM_5	0.19	0.38	-0.13	-0.27	-0.85	0.98
PM_{10}	-0.84	0.29	-0.25	0.24	0.20	0.96
$PM_{>10}$	-0.71	0.10	-0.34	0.03	0.57	0.95
Eigen Values	3.41	1.67	0.98	0.62	0.22	
%Total Variance	48.70	23.83	14.00	8.83	3.15	
% Cumulative Variance	48.70	72.53	86.53	95.36	98.51	

$PM_{0.44}$ and moderate for $PM_{0.88}$, $PM_{1.77}$ and PM_5 . The heavy loadings of $PM_{0.44}$ and $PM_{2.6}$ and significantly loaded for $PM_{0.88}$. These three factors together accounted for about 87% variance for solid particles at HP locations. Factor 4 appeared to be

biogenic source as it had loadings for $PM_{0.88}$, $PM_{1.77}$ and $PM_{2.6}$ (significant loading), PM_{10} and $PM_{>10}$. Factor 5 could be the domestic fuel burning as it had moderate loadings for $PM_{0.88}$, $PM_{1.77}$, $PM_{2.6}$, PM_{10} and $PM_{>10}$. These 5 factors together could explain 99% of solid particle concentrations at HP locations. The communality of these factors had also been almost unity that further established that the 5-factor model could be satisfactorily applied for HP locations.

At HU locations (Table 4.28), 3 factors were obtained with Eigen values above unity. The factor loadings at HU locations slightly differed with locations of MU. The Factor 1 could probably be identified as vehicular emissions but it had moderate factor loadings for $PM_{0.88}$, $PM_{1.77}$, PM_5 and PM_{10} and significant loadings for $PM_{2.6}$. HU showed bias for even bigger particles of $PM_{2.6}$ in comparison to MU locations for Factor 1. Over again, factor 2 could be the resuspended dust. It had significant loadings for $PM_{1.77}$ and moderate factor loadings for $PM_{2.6}$, PM_5 , PM_{10} and $PM_{>10}$. Factor 3 had high loadings for $PM_{2.6}$, PM_{10} and $PM_{>10}$ and as such, it appeared not solely due to gas-particle conversion factor but due to coagulation of these particles to bigger size groups. These three factors together accounted for about 84% variance in solid particles at HU locations. Factor 4 appeared to be biogenic source as it had loadings for $PM_{1.77}$, PM_5 , PM_{10} and $PM_{>10}$. Factor 5 could again be the domestic fuel burning as it had moderate loadings for $PM_{0.44}$, $PM_{0.88}$ and $PM_{2.6}$. These 5 factors together explained 99% of solid particle concentrations at HU locations. The communality of these factors was also almost unity that further established that the 5-factor model could be satisfactorily applied for HU location as well.

Table 4.28 Factor loadings for solid particles at HU locations

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
PM_{0.44}	-0.51	-0.66	-0.30	0.14	0.43	0.99
PM_{0.88}	0.07	-0.19	-0.24	-0.88*	0.34	0.99
PM_{1.77}	0.17	0.94*	-0.05	0.25	-0.11	0.99
PM_{2.6}	0.94*	0.24	0.21	-0.03	0.11	0.99
PM₅	0.06	0.07	-0.07	0.37	-0.92*	0.99
PM₁₀	0.21	0.01	0.96*	0.19	-0.04	0.99
PM_{>10}	-0.41	0.41	0.31	0.09	-0.74*	0.99
Eigen Values	3.10	1.78	1.01	0.59	0.51	
%Total Variance	43.86	25.42	14.50	8.38	7.25	
% Cumulative Variance	43.86	69.28	83.78	92.16	99.41	

From the results above, we observed that while 2 factors (with Eigen values at unity) were obtained for MP and HP locations, MU and HU had 3 such factors. As such, the plain locations of MP and HP had 2 major particulate sources corresponding basically to vehicular emissions and resuspension of street dust due to vehicular motions. The steep gradient locations of MU and HU had 3 factors (with Eigen values at unity), out of which 2 factors were common as observed for plain location and 3rd factor of gas-particle conversion reactions and coagulation particles factor that became important. The coagulation might get facilitated due to bias of vehicular emissions to emit bigger particles at steep gradient locations. Harrison *et al.* (1997) had also identified 3 major factors for PM_{2.5} and PM₁₀ as obtained by us. These factors were vehicular emissions, gas-particle conversion reactions and resuspension of surface dust.

We also attempted to obtain the significance of these 5-factors location wise at MP, MU, HP and HU locations. The results of the same were provided at Appendix-IV (Tables A.4.12 to Table A.4.15). Vehicular emissions appeared to be the most important factor for solid particle concentrations as factor 1 had high loadings at MP, MU, HP and HU locations. The factor 1 i.e. vehicular emissions alone could explain solid particle concentration of about 62% at MP locations, 75% at MU locations, 89% at HP locations, and 90% at HU locations. Factor 2 that represented resuspended dust appeared to have significant loading at MP and MU locations where about 24% and 10% concentrations of solid particles respectively appeared to be associated with this factor. The remaining factors appeared not to be that significant at these locations compared to factor 1 and factor 2.

The Pearson correlation coefficients for pair-wise comparison of MP, MU, HP and HU locations on the basis of the solid particle concentrations are given at Appendix-IV (Tables A.4.16 to A.4.19). The correlations between the MP locations (Table A.4.16) were strongest between most of the locations with correlation coefficients (r) near unity and significant ($p < 0.05$) excluding the location of MP11, which did not show high relationships with other MP locations. Some other MP locations like MP4, MP8, MP9, MP10, MP11 and MP12 also showed comparatively weaker relationships. These locations (excluding MP4) were situated on other artillery roads and were located at highly commercial area of Barabazar. The locations of MP1, MP2, MP3, MP5, MP6, MP7 and MP13 that showed strong correlations were located on highway. The correlations between the MU locations (Table A.4.17) were strong between most of the locations with correlation

coefficients (r) near unity and significant ($p < 0.05$) excluding the location of MU5, which did not show high relationships with other MU locations. Likewise MU3 and MU6 also showed somewhat weaker relationships with certain MU locations. The correlations between HP locations (Table A.4.18) were also strong between most of the locations with correlation coefficients (r) near unity and significant ($p < 0.05$) excluding the location of HP11, which did not show high relationships with other HP locations. This location was located at educational centre place with high vehicular and pedestrian activities. The correlations between HU locations (Table A.4.19) were strong as almost all locations had correlation coefficients (r) near unity and significant ($p < 0.05$). The high pair-wise correlation coefficients (r) among the various locations of MP, MU, HP and HU on the basis of solid particle concentrations was expected due to similarities in their characteristics. Burton *et al.* (1996) also found similar strong correlation coefficients (r) at various locations in metropolitan of Philadelphia on the basis of the atmospheric particulate concentrations classified by them as $PM_{2.5}$, coarse particles ($2.5 < d_a < 10 \mu m$) and inhalable PM_{10} .

4.5.5 Relationship of solid particles with meteorological variables

Excluding the control locations of CB, other locations of MP, MU, HP and HU had vehicular activities as major of source of particle build up as was observed in the sub-section 4.5.4 above. Since these activities were location-specific and increase in particle concentrations was sudden. It was felt necessary to understand the extent of the association of meteorological variables with the concentration of

solid particles of various size groups. As such, Pearson correlation coefficients (r) of suspended particulates at CB, MP, MU, HP and HU locations with meteorological variables of ambient temperature, RH, WS and WD were examined.

The correlation of ambient temperature with $PM_{0.44}$ (Table 4.29) was highly positive and significant ($p < 0.05$) at CB locations and moderately positive at MP locations while it was negative at MU, HP and HU locations thus showing a gradual decrease in temperature and $PM_{0.44}$ relationship. It implied that at low particle concentrations, temperature assisted Brownian movement of particulates but as the particle concentration increased other factors like diffusion and coagulation became influencing factors. The relationship of temperature with $PM_{0.88}$ was positive but weak at MP locations and negative at CB, MU, HP and HU locations. Likewise, the relationship of temperature with $PM_{1.77}$ was positive but weak at MU locations and negative at CB, MP, HP and HU locations. The relationship of temperature with $PM_{2.6}$ was negative and significant ($p < 0.05$) at CB and MU locations and moderately negative at MP locations while it was positive but weak at HP and HU locations. The relationship of temperature with cumulative $PM_{2.5}$ was positive but weak at CB and MP locations and moderately negative at MU, HP and HU locations. The relationship of temperature with cumulative $PM_{2.5}$ at CB and MP locations appeared to increase with increasing temperature while the same was not applicable at MU, HP and HU locations where the concentration of cumulative $PM_{2.5}$ was governed by vehicular activities. Harrison *et al.* (1997) obtained almost similar relationships between temperature and $PM_{2.5}$ (0.14) in Birmingham as were found at CB and MP while Monn *et al.* (1999) observed highly positive (0.94) and significant

relationships ($p > 0.05$) in Switzerland. The relationship of temperature with PM_5 was highly negative at CB and moderately negative at MP locations while positive at MU, HP and HU locations (0.17, 0.03 and 0.49 respectively). The relationship of temperature with PM_{10} was highly positive at CB locations and moderately positive at HP locations while it was negative at MP, MU and HU locations. Again, Harrison *et al.* (1997) obtained almost similar relationships between temperature and PM_{10} (0.23) in Birmingham as were found by us for HP locations (0.26) while Monn *et al.* (1999) observed highly positive (0.94) and significant relationships ($p > 0.05$) in Switzerland similar as obtained for CB locations (0.99). The relationship of temperature with $PM_{>10}$ was positive at all the locations signifying that increase in temperature also increased the $PM_{>10}$ concentrations.

Table 4.29 Pearson correlation coefficients (r) between solid particles and ambient temperature								
Location	$PM_{0.44}$	$PM_{0.88}$	$PM_{1.77}$	$PM_{2.6}$	Cum $PM_{2.5}$	PM_5	PM_{10}	$PM_{>10}$
CB	1.00*	-0.90	-0.79	-1.00*	0.01	-0.89	0.99	0.41
MP	0.39	0.04	-0.17	-0.35	0.07	-0.16	-0.10	0.05
MU	-0.03	-0.00	0.11	-0.66*	-0.11	0.17	-0.04	0.20
HP	-0.09	-0.26	-0.21	0.12	-0.27	0.03	0.26	0.20
HU	-0.31	-0.35	0.50	0.14	-0.23	0.49	-0.28	0.19

* Significant correlation ($P < 0.05$)

The correlations of RH with $PM_{0.44}$ (Table 4.30) were moderately positive at HU locations and negative at CB, MP, MU and HP locations thus showing a gradual increase in RH and $PM_{0.44}$ relationship signifying inverse association. The relationship of RH with $PM_{0.88}$ was highly positive at CB locations and positive but weak at MP locations while it was negative at MU, HP and HU locations thus

showing a gradual decrease in RH and $PM_{0.88}$ relationship. The relationship of RH with $PM_{1.77}$ was highly positive at CB locations, moderately positive at MP and HP locations, positive but weak at HU locations and negative at MU locations. The relationship of RH with $PM_{2.6}$ was highly positive at CB locations, moderately positive at MP and MU locations and negative at HP and HU locations. The positive relationships of $PM_{0.88}$, $PM_{1.77}$ and $PM_{2.6}$ at most of the locations clearly indicated that coagulation of fine particles was assisted by humid conditions. The relationship of RH with cumulative $PM_{2.5}$ was moderately positive at CB locations, positive but weak at HP locations and negative at MP, MU and HU locations. Harrison *et al.* (1997) obtained relationships of 0.17 between RH and $PM_{2.5}$ while we obtained the relationships of 0.39 at CB locations, which was comparable. The relationship at MP, MU, HP and HU locations did not show any specific trends. The relationship of RH with PM_5 was highly positive and significant at CB locations, moderately positive at MP, MU and HU locations and negative at HP locations. The relationship of RH with PM_{10} was highly negative at CB locations, negative and significant ($p>0.05$) at HU locations, moderately positive at MU and positive but weak at MP and HP locations. Harrison *et al.* (1997) obtained a relationship of 0.11 between RH and PM_{10} in Birmingham in comparison to the correlation of 0.27 found by us at MU locations. The relationship of RH with $PM_{>10}$ was negative at CB and MP locations and positive at MU, HP and HU locations signifying no definite pattern of relationship between RH and particle concentrations but it implied that an increase in RH decreased the concentration of particulate concentrations perhaps as heavier particulates settled fast in humid condition. This also explained the negative

Table 4.30 Pearson correlation coefficients (r) between solid particles and relative humidity								
Location	PM_{0.44}	PM_{0.88}	PM_{1.77}	PM_{2.6}	Cum PM_{2.5}	PM₅	PM₁₀	PM_{>10}
CB	-0.89	0.65	0.97	0.91	0.39	1.00*	-0.86	-0.74
MP	-0.37	0.04	0.23	0.15	-0.05	0.26	0.02	-0.11
MU	-0.22	-0.13	-0.21	0.33	-0.22	0.29	0.27	0.02
HP	-0.22	-0.13	0.45	-0.01	0.06	-0.33	0.06	0.15
HU	0.23	-0.19	0.16	-0.49	-0.04	0.28	-0.63*	0.32

* Significant correlation ($P < 0.05$)

correlation with PM_{>10} at certain locations. Highly humid conditions helped in faster coagulation process and made hygroscopic particles gain bigger size, which was evident by the positive correlations of RH with PM_{2.6}, PM₅, PM₁₀ and PM_{>10}.

The relationship of WS with PM_{0.44} (Table 4.31) was highly positive at CB locations, moderately positive at HU locations and negative at MP, MU and HP locations. The relationship of WS with PM_{0.88} was positive but weak at HP locations and negative at CB, MP, MU and HU locations. The relationship of WS with PM_{1.77} was moderately positive at MU and HU locations and negative at CB, MP and HP locations. The relationship of WS with PM_{2.6} was positive but weak at HP locations and negative at CB, MP, MU and HU locations. The relationship of WS with cumulative PM_{2.5} was moderately positive at CB locations and negative at MP, MU, HP and HU locations. The negative relationship of WS with cumulative PM_{2.5} indicated that the concentration of these size fraction particulates decreased with high wind speed conditions. Harrison *et al.* (1997) obtained relationships of -0.50 between WS and PM_{2.5} in Birmingham while Lam *et al.* (1999) obtained the relationships of 0.49 in Hong Kong. Our findings ranged from a moderately positive relationship (0.26) at CB locations to moderately negative relationship (-0.46) at HP

locations and as such, the findings were similar to these workers. The relationship of WS with PM_5 was moderately positive at MP, MU and HU locations and negative at CB and HP locations. The relationship of WS with PM_{10} was highly positive at CB locations and moderately positive at MP, MU, HP and HU locations. Harrison *et al.* (1997) obtained relationship of -0.32 between WS and PM_{10} in Birmingham while Lam *et al.* (1999) obtained the relationships of 0.49 in Hong Kong. Our findings ranged from a moderately positive relationship (0.10) at HU locations to highly positive (0.99) at CB locations. The relationship of WS with $PM_{>10}$ were also moderately positive at CB, MP, MU, HP and HU locations. The moderately positive correlations with PM_{10} and $PM_{>10}$ at all the locations signified that these size fraction particulates were added to the atmosphere during windy conditions.

Table 4.31 Pearson correlation coefficients (r) between solid particles and wind speed								
Location	$PM_{0.44}$	$PM_{0.88}$	$PM_{1.77}$	$PM_{2.6}$	Cum $PM_{2.5}$	PM_5	PM_{10}	$PM_{>10}$
CB	0.98	-0.98	-0.62	-0.97	0.25	-0.76	0.99	0.18
MP	-0.14	-0.23	-0.45	-0.19	-0.33	0.32	0.27	0.32
MU	-0.09	-0.31	0.26	-0.47	-0.26	0.18	0.19	0.33
HP	-0.19	0.01	-0.53	0.08	-0.46	-0.03	0.44	0.43
HU	0.09	-0.38	0.19	-0.45	-0.32	0.14	0.10	0.46

* Significant correlation ($P < 0.05$)

The relationship of WD with $PM_{0.44}$ (Table 4.32) was moderately positive at MP and MU locations and negative at CB, HP and HU locations. The relationship of WD with $PM_{0.88}$ was highly positive at CB and MU locations, moderately positive at MP and HU locations and negative at HP locations. The relationship of WD with $PM_{1.77}$ was highly positive at CB and HP locations,

moderately positive at MP locations, positive but weak at HU locations and negative at MU locations. The relationship of WD with $PM_{2.6}$ was highly positive and significant ($P > 0.05$) at HU locations, highly positive at CB locations, moderately positive at MP and HP locations and positive but weak at MU locations. Positive relationships of $PM_{0.88}$, $PM_{1.77}$, $PM_{2.6}$ with WD at most of the locations implied that the concentration of these particles increased with favorable direction conditions. The relationship of WD with cumulative $PM_{2.5}$ was moderately positive at MP and MU locations, positive but weak at HU locations and negative at CB and HP locations. We observed (Chapter-2) that WD during sampling changed frequently with the most prevalent wind from ENE to almost N direction. Though the city centre-line runs almost in a NW-SE direction and two CB locations were located in the south direction but the relationship between WD with cumulative $PM_{2.5}$ was negative implying that the impact of the emission activities in city had hardly any impact at these locations. The relationship of WD with PM_5 was highly positive at CB locations, positive but weak at HU locations and negative at MP, MU and HP locations. The highly positive relationship of WD with PM_5 at CB location was quite significant as most of the particles of biological origin belonged to this size group. As thick forests surrounded the CB locations, it was likely that these sources might be a contributing factor for PM_5 . The relationship of WD with PM_{10} was moderately positive at HP locations, positive but weak at HU locations and negative at CB, MP and MU locations. The relationship of WD with $PM_{>10}$ was positive but weak at HP locations and negative at CB, MP, MU and HU locations.

Table 4.32 Pearson correlation coefficients (r) between solid particles and wind direction								
Location	PM_{0.44}	PM_{0.88}	PM_{1.77}	PM_{2.6}	Cum PM_{2.5}	PM₅	PM₁₀	PM_{>10}
CB	-0.98	0.98	0.62	0.97	-0.25	0.76	-0.99	-0.18
MP	0.49	0.29	0.35	0.31	0.51	-0.32	-0.44	-0.60*
MU	0.27	0.54	-0.32	0.01	0.43	-0.45	-0.46	-0.20
HP	-0.43	-0.27	0.52	0.41	-0.03	-0.28	0.24	0.02
HU	-0.42	0.23	0.06	0.73*	0.12	0.06	0.04	-0.37

* Significant correlation (P<0.05)

4.5.6 Solid particle size distributions with image analysis system

One of the major problems in determination of particle size distribution with optical microscope is the precision in the data due to influence of operator's performance. IAS is such an automated computerized electro-optic device that measures the fine particle images with speed, sophistication and precision. It cannot only determine the "Feret's diameter" of particles but can also measure various other characteristics. The particle length, breadth, area, perimeter and roundness are a few parameters that can be determined with IAS. IAS also provides digital images and this helps in understanding the configuration, structure and morphology of the particles.

We had attempted to determine the divergence in particle size distributions acquired with optical microscopy and IAS. The exercise was performed to assess the difference, if any, in data sets and to verify the results obtained with optical microscope. Some samples were randomly selected for CB, MP, MU, HP and HU locations for comparison. The comparison of particle size results obtained with optical microscopy and IAS techniques are provided in (Tables A.4.20 to A.4.28). Out of the two data sets for CB1, (Table A.4.20), the minimum SD of 0.0% was

observed for $PM_{>10}$ (Nov 97-May 98) and $PM_{2.6}$ (Nov 98-May 99) and maximum SD of 2.8% was obtained for $PM_{0.88}$ (Nov 98-May 99). At MP7 and MP9 (Tables A.4.21 & A.4.22), the minimum SD of 0.0% was observed for $PM_{0.44}$ at MP7 (Oct 98) and maximum SD of 8.3% for PM_{10} at MP 9 (Nov 98-May 99). At MU3 and MU11 (Tables A.4.23 & A.4.24), the minimum SD of 0.1% was observed for $PM_{0.44}$ (Nov 97-May 98) and for $PM_{2.6}$ (Nov 97-May 98) both at MU3 and maximum SD of 3.7% for $PM_{0.88}$ at MU3 (Nov 98-May 99). Likewise at HP3 and HP8 (Tables A.4.25 & A.4.26), the minimum SD of 0.0% was observed for PM_{10} at HP3 (Nov 98-May 99) and maximum SD of 9.0% for $PM_{2.6}$ also at HP3 (Nov 98-May 99). At HU5 and HU7 (Tables A.4.27 & A.4.28), the minimum SD of 0.1% was observed for $PM_{2.6}$ (Nov 98-May 99), PM_{10} (Nov 98-May 99) and $PM_{>10}$ (Nov 98-May 99) all at HU5 and maximum SD of 4.8% for $PM_{0.44}$ also at HU5 (Oct-98). As such, we observed that the maximum SD of 9.0% was observed out of the 26 samples taken for 9 numbers of CB, MP, MU, HP and HU locations. Another fact that needs to be mentioned here that it was not likely that the same portions of the slides (containing particle samples) were assessed by optical microscope and IAS thus giving small variations in particle size distributions. Of course, these variations were not very substantial considering the volume of data compared for the purpose. This also established the fact that though the technique for determination of particle size distributions with an optical microscope was a little time consuming but it provided almost similar results as were obtained with the help of sophisticated IAS and, as such, former might be applied with precision and accuracy where such computerized electro optic devices were not available.

By IAS, one can perform various analyses. We obtained individual particle's length, breadth, area, perimeter and roundness for some samples of CB, MP, MU, HP and HU locations. Only mean values for these assessed parameters is provided in (Table A.4.29). We observed that the smallest measured particle was having the length of 0.88 μm breadth of 0.44 μm , area of 0.78 μm^2 , perimeter of 3.54 μm with roundness of 1.11. The biggest particle observed at HU locations, had length of 224.34 μm , breadth of 154.87 μm , area of 9493.50 μm^2 , perimeter of 5677.43 μm with roundness of 253.94. One distinguished observation that could be made here was that the maximum particle size increased from MP locations to HU locations. We had observed earlier (Chapter-3) that the soot concentration increased from MP locations to HU locations due to increase in vehicular activities and hilly terrain characteristics. It appeared that increase in soot particle concentrations also increased the coagulation processes due to availability of large number of particles facilitated by the high humid conditions of Shillong. The standard deviations were small while standard errors were almost insignificant in the data set.

The digital images obtained for CB, MP, MU, HP and HU locations are provided in Fig. 4.35 to 4.39. A distinct difference in the types of suspended particulates was visible from these images. The suspended particles were sparse at CB locations (Fig. 4.35) and prevalent particles appeared to be mostly dust, pollens and oil-drops. At MP locations (Fig. 4.36), density of soot and resuspended dust particles increased with more variations in shapes and sizes. The density of fine soot particles increased at MU locations (Fig. 4.37) though resuspended dust particles were also visible. The characteristics of suspended particulates changed further at

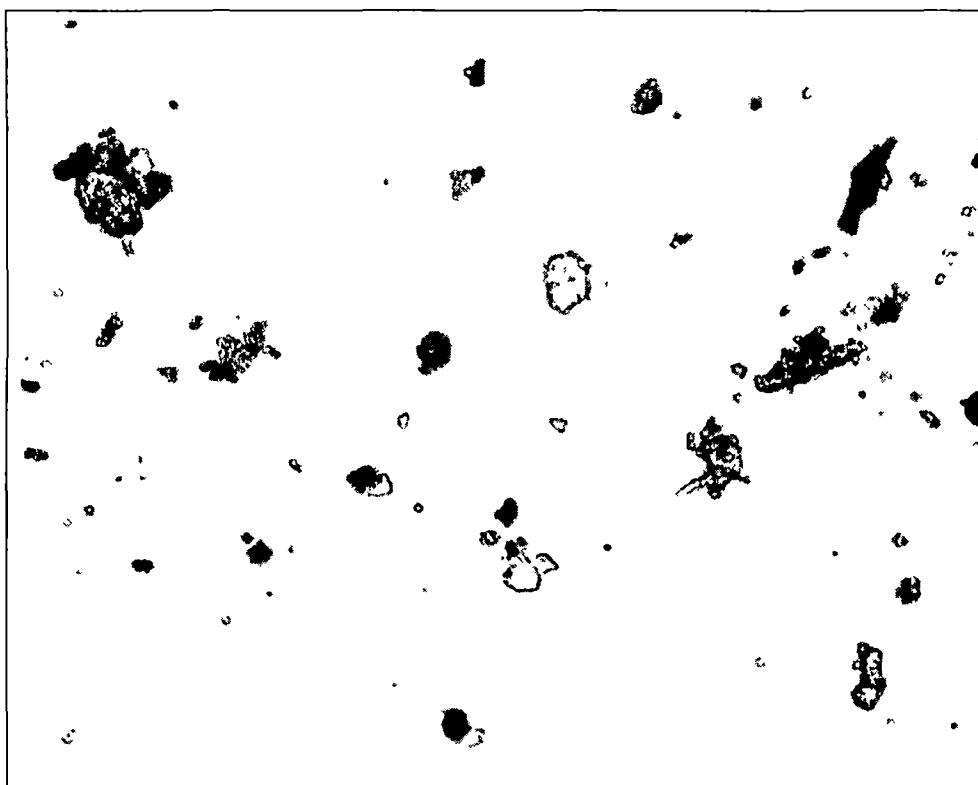


Fig. 4.35 Image of suspended particulates at CB locations

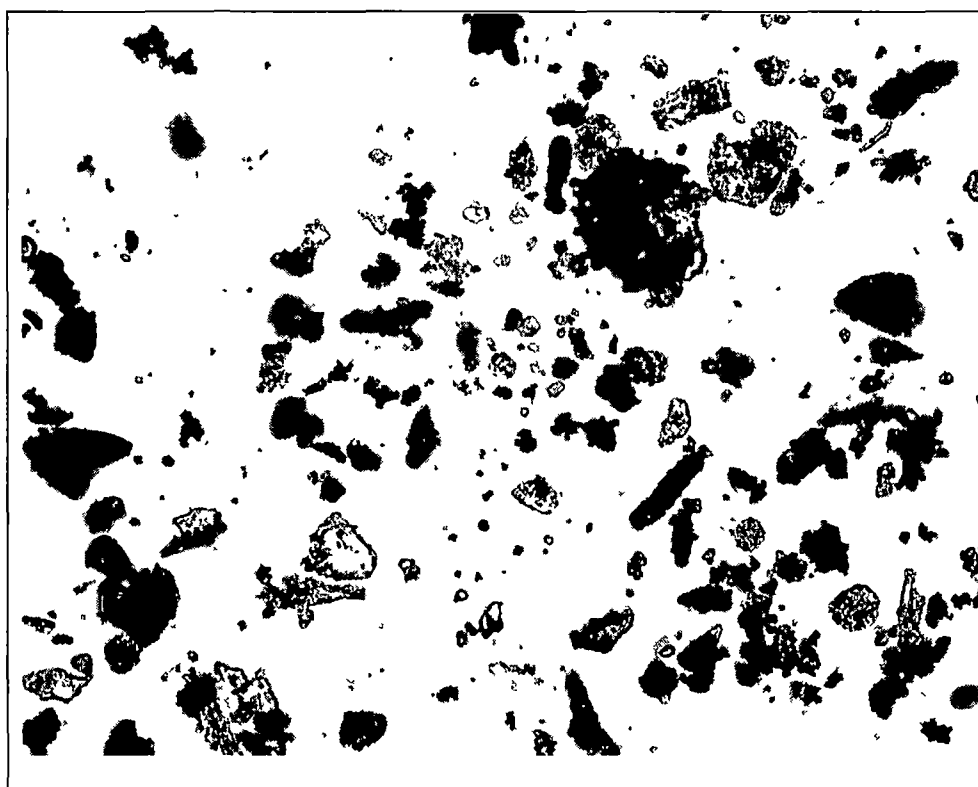


Fig. 4.36 Image of suspended particulates at MP locations

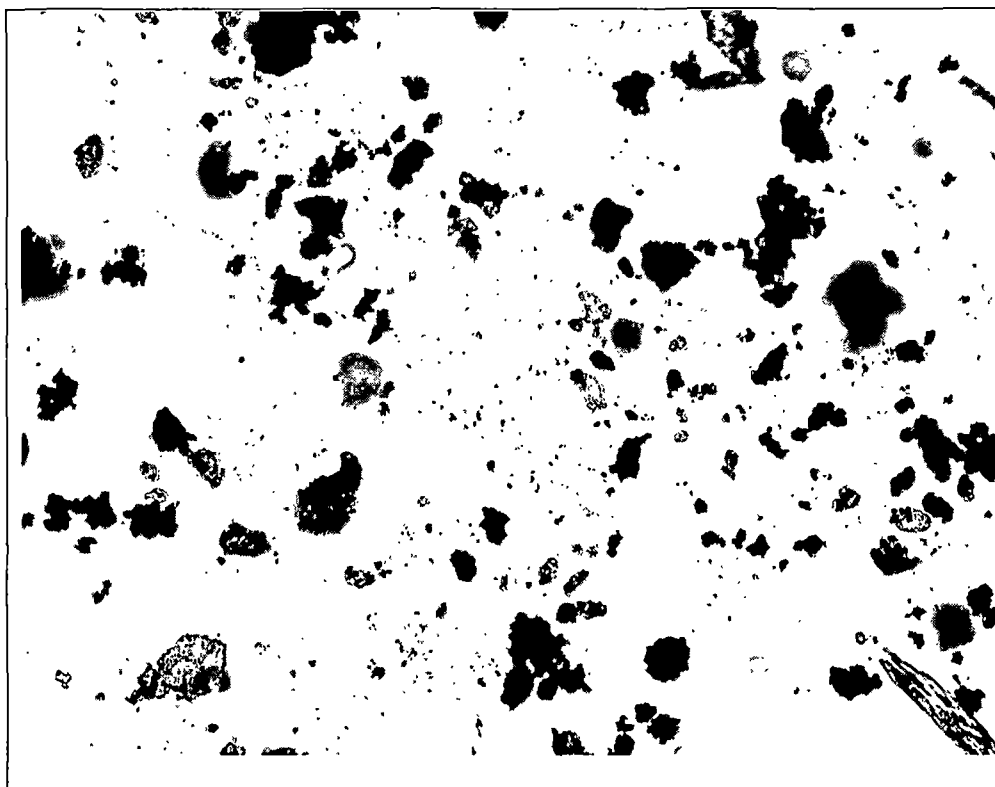


Fig. 4.37 Image of suspended particulates at MU locations

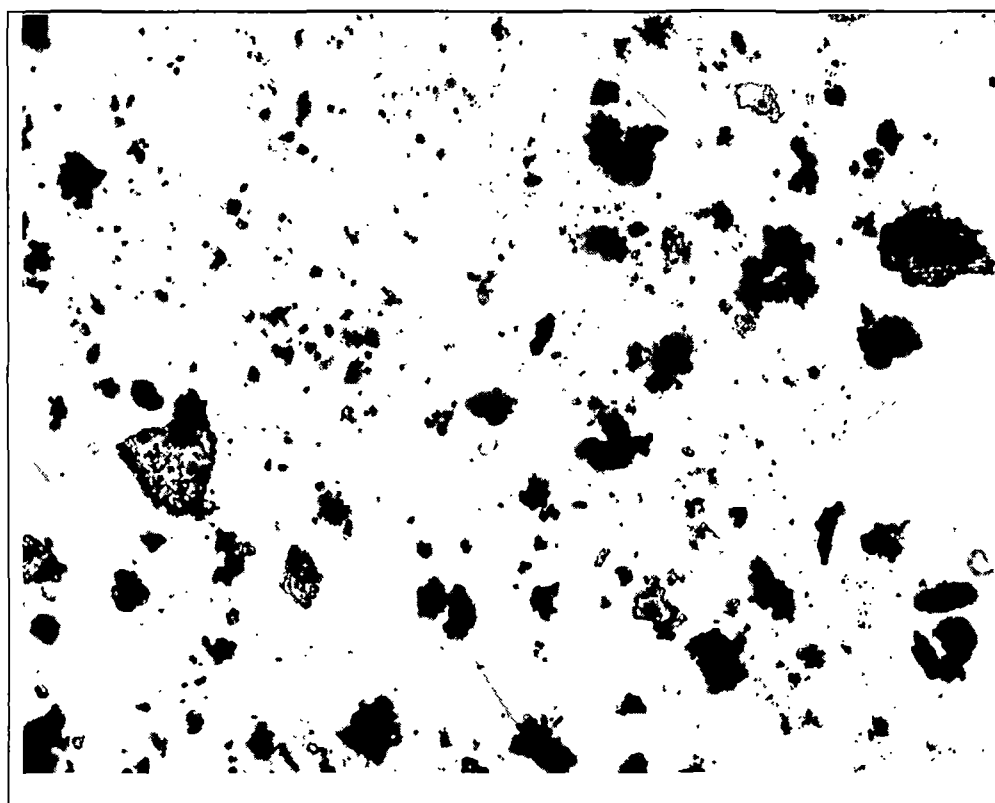


Fig. 4.38 Image of suspended particulates at HP locations

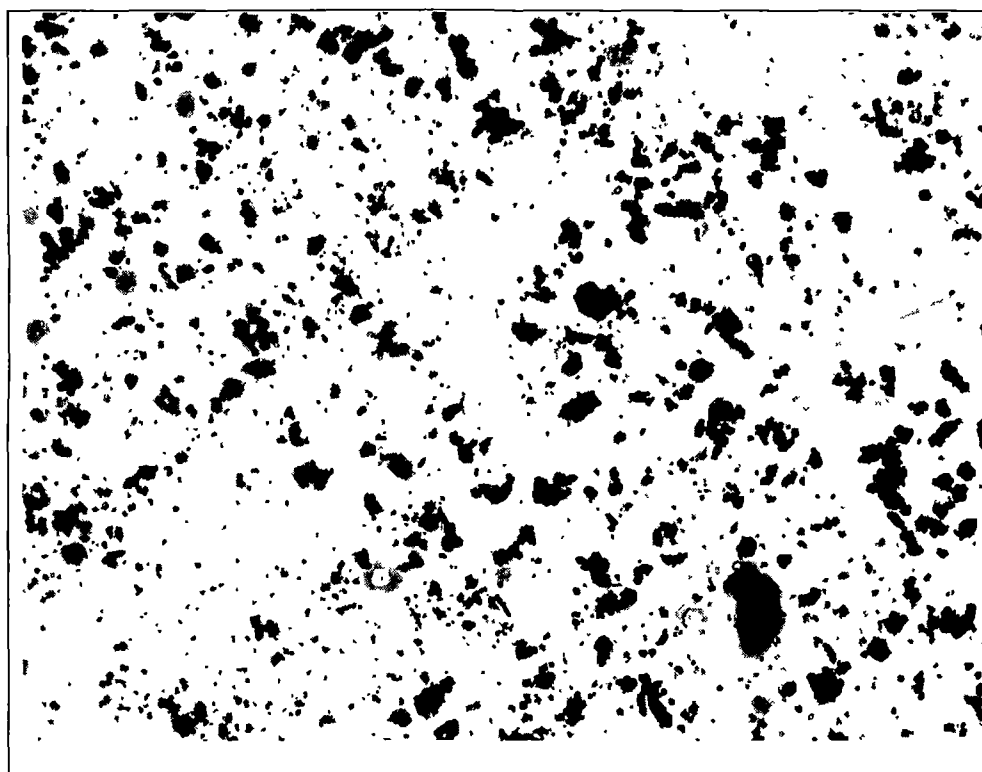


Fig. 4.39 Image of suspended particulates at HU locations

HP locations (Fig. 4.38) with more fine soot particles as well as bigger particles of dark color that appeared to be conglomerates of soot particulates. The marked difference in the images of suspended particulates was visible at HU locations (Fig. 4.39) where the most prevalent particulates were fine soot particle and its conglomerates.

4.5.7 Solid particulate morphology with scanning electron microscope

Since different sources emit particles in different size ranges (Buerki *et al.*, 1989) individual particle morphology reflects the nature and origin of these contributing sources. The particle morphology and textural relationships are also important in order to assess their interactions with the environment, as non-spherical

particles will have longer atmospheric residence time than typical spherical particles. Though, we analyzed digital images obtained by the IAS as discussed in the subsection 4.5.6 above, but these images could hardly provide clear morphological structures of individual particles due to limitations of magnification, and as such, we also analyzed some randomly selected samples from CB, MP, MU, HP and HU locations. The photomicrographs of these locations were taken by the SEM and were provided at Fig. 4.40 to 4.44 respectively.

A few cone shaped crustal particles were visible at CB locations (Fig. 4.40). A typical crustal particle with an irregular block-like shape was visible. Zou *et al.* (1997) had found such shapes to have high levels of Si, Al, and Ca with some S and Fe, which were indicators of its soil related origin. A distinctive round shape particle of about 5- μm diameter with small spikes was also visible which appeared to be of biogenic origin. The prevalence of such particles at CB locations was quite expected due to their proximity to the thick vegetation. Some other particles of smaller shapes were also visible which appeared to be crustal shards.

The particle structure became clearer at MP locations (Fig. 4.41). Typical crustal particles with irregular shapes were visible with smaller particles embedded on them. Some porous fluffy loose structures were also seen which were soot particles emitted from vehicular exhaust. Some rods shaped structures were also visible which appeared to be crustal shards. The particles at MP locations clearly appeared to be a mixture of crustal and vehicular emission particles.

The particle structure at MU locations (Fig. 4.42) changed with a bias towards more porous fluffy loose structures of soot particles, which appeared to be

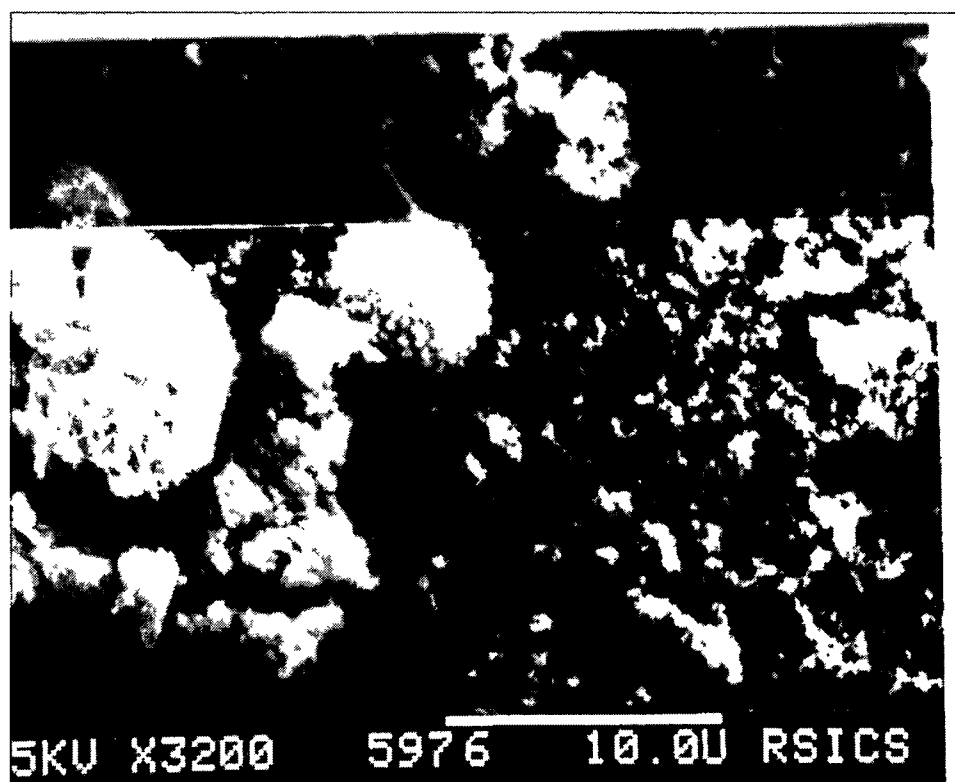


Fig. 4.40 Photomicrograph of suspended particulates at CB locations

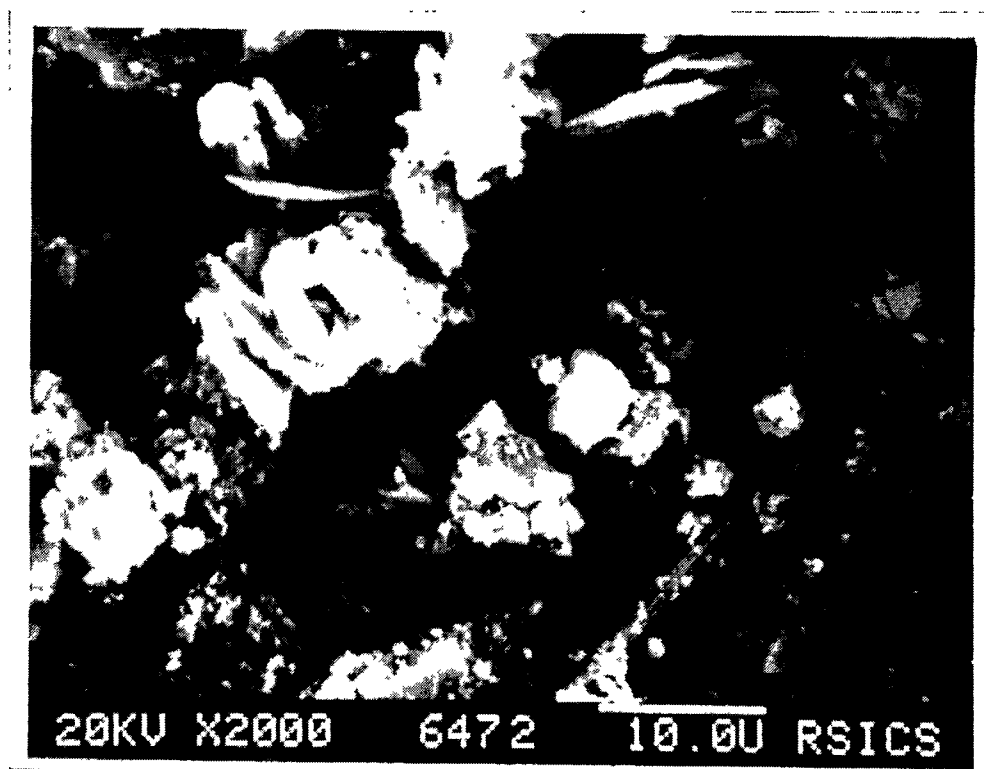


Fig. 4.41 Photomicrograph of suspended particulates at MP locations

conglomerates of the smaller particles. These conglomerates were perhaps formed because soot particles had definite tendency to stick together in chains and form fluffy clusters quite fast in the atmosphere (Meetham *et al.*, 1981). Such conglomerates were found to have a concentric circular structure of discontinuous fringes with inter-planer spacing (Rietmeijer *et al.*, 1997). Some very fine particles

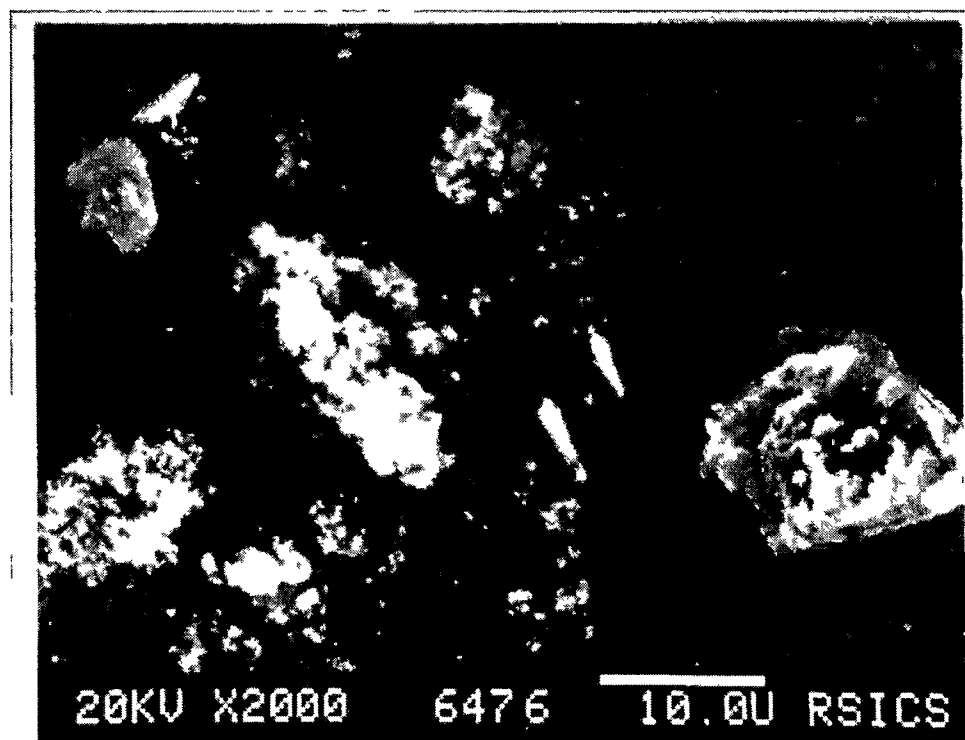


Fig. 4.42 Photomicrograph of suspended particulates at MU locations

(<0.5 μ m) particles were also seen in the photomicrograph. A few crustal particles with irregular shapes and smaller particles embedded on them were also visible.

We observed that smaller size particles became more prevalent at HP locations (Fig. 4.43). Apart from the crustal particles of irregular shapes and porous fluffy loose structures of soot, some round shaped particles were also seen. These

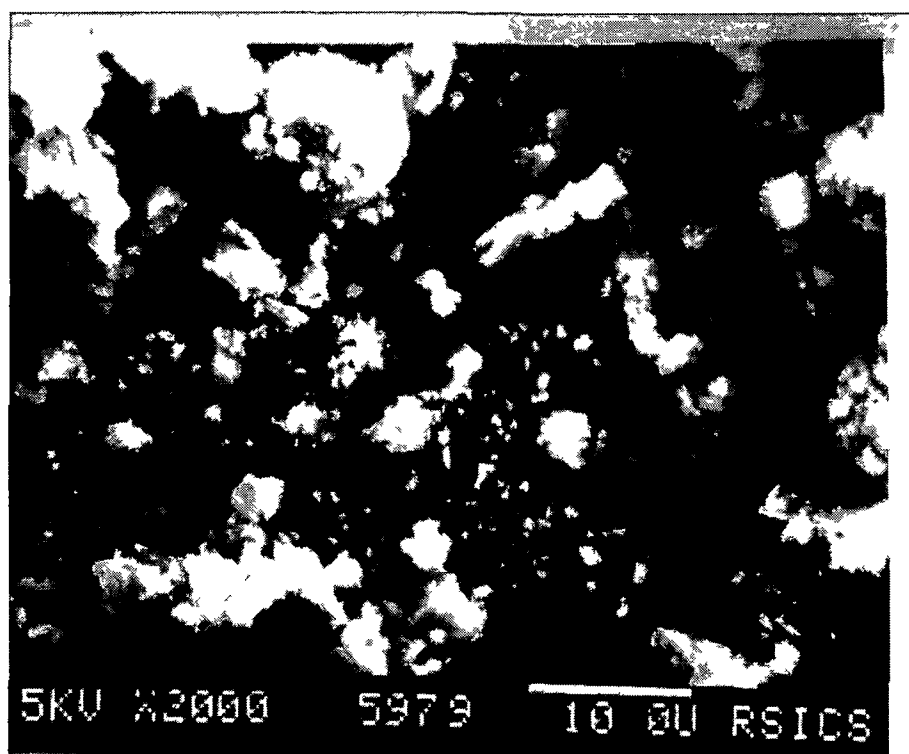


**Fig. 4.43 Photomicrograph of suspended particulates
at HP locations**

spherical particles with minor attachments on the surface are sized at about 10 μm . These appeared to have originated from some metal fabrication process (welding etc.) involving high temperatures (Lichtman *et al.*, 1985).

It was observed that the concentration of fine particles became even further prevalent at HU locations (Fig. 4.44). The crustal particles of irregular shapes with smooth surfaces, porous fluffy loose structures of soot and some round shaped particles were seen here as well. The spherical particles with minor attachments on the surface originated from some metal fabrication process could also be seen. Some very fine particles ($<0.5\mu\text{m}$) particles were also visible together with few crustal particles with irregular shapes and smaller particles embedded on them.

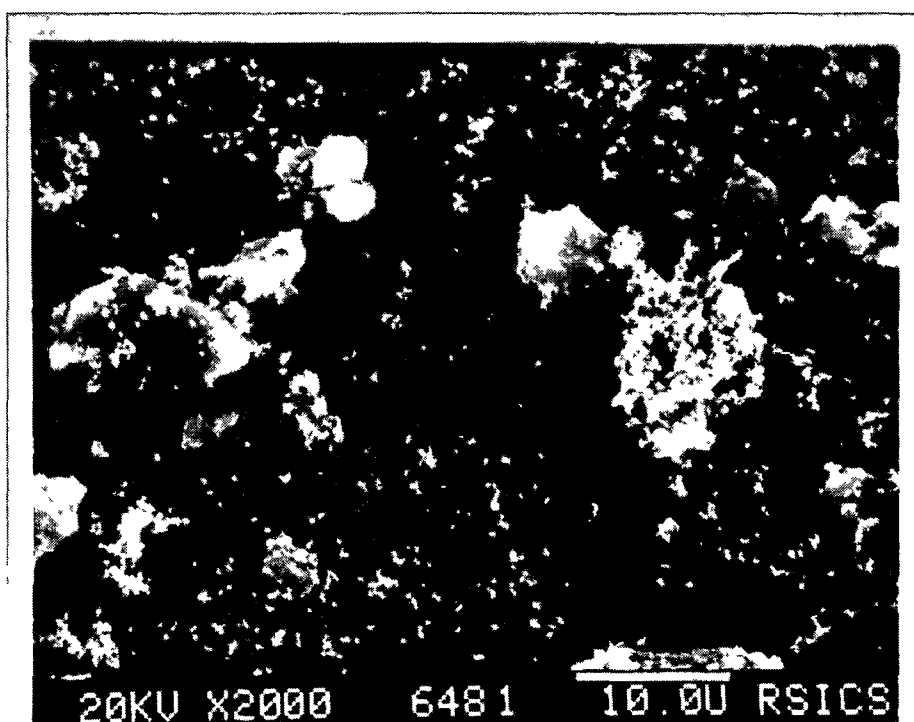


**Fig. 4.44 Photomicrograph of suspended particulates
at HU locations**

Vehicular emissions were considered as the major source of particulate build up in Shillong. Vehicles running on different kind of fuel-operated engines invariably emit particles of different size ranges and morphological structures. Understanding individual particle morphology of vehicular exhaust was felt necessary to assess their interaction behaviour with the environment and health hazard potential. We had analyzed the exhaust particulate morphology emitted by diesel and petrol driven vehicles.

The photomicrograph of diesel particulate is given at Fig. 4.45. The particulate appeared black in color with a porous fluffy loose structure and as such appeared to be consisted of carbon particles. These amorphous soot units were arranged in chains and clusters. These units also appeared to have a concentric

circular structure of discontinues fringes with solid core of carbon particles, organic fractions, sulfates and some trace elements. They seemed to be primarily due to incomplete combustion of diesel fuel in poorly maintained vehicles. Such particles were also observed in plenty at the traffic related locations in Shillong.

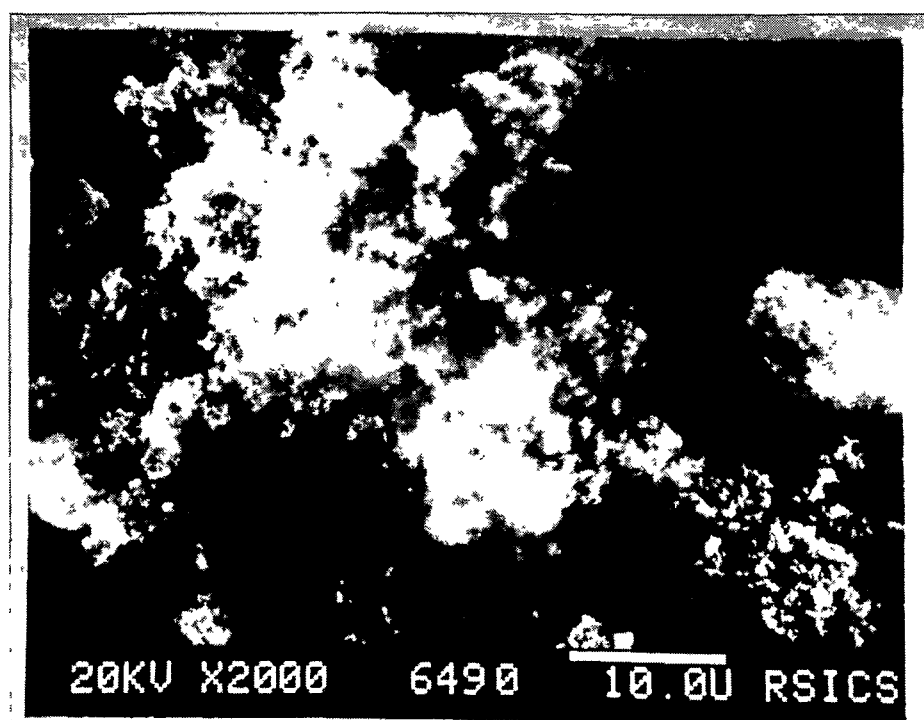


Fig. 4.45 Photomicrograph of particulates from diesel vehicle exhaust emissions

The photomicrograph of petrol vehicular exhaust particulates particulate is given at Fig. 4.46. In comparison to the soot particles from the diesel exhaust, the petrol exhaust particulates appeared to be more compact in nature but irregular in shape. It appeared to be consisted of carbon core with various organic compounds and trace elements associated with it. These types of particles were also observed at traffic related locations in Shillong.

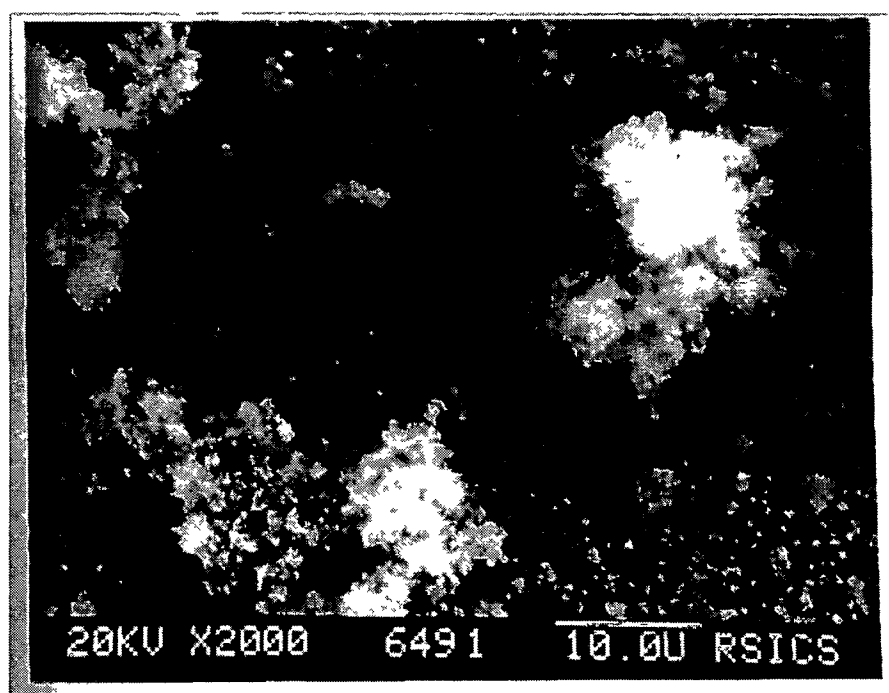


Fig. 4.46 Photomicrograph of particulates from petrol vehicle exhaust emissions

4.5.8 Size distributions of oil-drops

The average values for size distributions of fine oil-drop spectra ($OD_{2.5}$) are given in Table 4.33. The relative abundance of $OD_{0.44}$ at CB locations was 4.7%. The concentration of $OD_{0.44}$ increased at traffic activity related locations of HP where it was 5.3% while it decreased at MP, MU and HU locations where it had been 2.8%, 2.6% and 3.6% respectively. The relative abundance of $OD_{0.44}$ at TIF0 was 5.6% while it was nil at TIB0 and TIG0 locations. The concentration of $OD_{0.44}$ at H an IN locations was nil. The relative abundance of $OD_{0.44}$ at IE locations was 5.8% while it was 3.2% at A0 location. The concentration of $OD_{0.88}$ was 51.8% at CB locations. Thus, a spontaneous increase in concentration of $OD_{0.88}$ could be observed in comparison to $OD_{0.44}$ concentrations. Like CB locations, the

Table 4.33 Distribution of OD_{2.5} in Shillong (% relative abundance)

S No	Location	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size
		Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
1	CB	4.7 ± 6.1	11.8	51.8 ± 1.6	52.8	30.7 ± 5.1	34.9	8.8 ± 1.7	9.9	6
2	MP	2.8 ± 0.0	7.5	42.9 ± 10.5	66.8	39.8 ± 8.6	49.9	7.2 ± 3.9	15.5	31
3	MU	2.6 ± 4.1	13.6	40.3 ± 10.7	62.1	40.1 ± 11.6	52.8	10.3 ± 4.4	18.4	27
4	HP	5.3 ± 8.5	27.9	41.3 ± 5.6	50.3	38.7 ± 11.3	58.3	7.7 ± 3.4	13.9	35
5	HU	3.4 ± 3.0	8.0	41.4 ± 9.5	61.5	40.3 ± 6.4	51.7	8.5 ± 4.4	17.9	26
6	TIF0	5.6 ± 7.8	11.1	62.1 ± 8.1	76.5	26.0 ± 10.4	33.3	5.4 ± 7.6	10.8	2
7	TIB0	0.0 ± 0.0	0.0	53.6 ± 13.5	63.1	36.8 ± 21.6	52.0	8.9 ± 6.9	13.8	2
8	TIG0	0.0 ± 0.0	0.0	73.4 ± 5.9	77.7	26.7 ± 5.9	30.8	0.0 ± 0.0	0.0	2
9	H	0.0 ± 0.0	0.0	48.4 ± 23.8	65.3	46.0 ± 18.0	58.7	1.4 ± 2.0	2.8	4
10	IN	0.0 ± 0.0	0.0	52.2 ± 8.6	58.3	39.9 ± 1.6	41.0	4.0 ± 2.7	6.1	4
11	IE	5.8 ± 1.1	6.6	37.9 ± 0.8	38.5	40.2 ± 6.4	44.7	11.0 ± 2.8	12.9	4
12	A0	3.2 ± 4.5	6.3	65.6 ± 4.3	68.6	24.9 ± 8.9	31.2	5.4 ± 7.6	10.8	2

concentration of OD_{0.88} also showed sudden increasing trends at traffic activity related locations. The relative abundance of PM_{0.88} at MP, MU, HP and HU locations was 42.9%, 40.3%, 41.3% and 41.4% respectively, thereby recording a decrease in PM_{0.88} concentrations in comparison to the CB locations. The relative abundance of PM_{0.88} at TIF0, TIB0 and TIG0 was 62.1%, 53.6% and 73.4% respectively. The concentration of OD_{0.88} at H and IN locations was 48.4% and 52.2% respectively. The concentration of OD_{0.88} at IE locations was 37.9% while it was

65.6% at A0 location. The relative abundance of OD_{1.77} at CB locations was 30.7%. At MP, MU, HP and HU locations, OD_{1.77} concentration was 39.8%, 40.1%, 38.7% and 40.3% respectively. A distinct pattern was evident from these observations as the concentration of OD_{1.77} was more at MP, MU, HP and HU locations in comparison with CB locations. The concentration of OD_{1.77} at TIF0, TIB0 and TIG0 locations was 26.0%, 36.8% and 26.7% respectively. The concentration of OD_{1.77} at H and IN locations was 46.0% and 39.9% respectively. The concentration of OD_{1.77} at IE locations was 40.2% while it was 24.9% at A0 location. The relative abundance of OD_{2.6} was 8.8% at CB locations that increased to 10.3% at MU locations but was slightly less at MP, HP and HU locations in comparison to CB locations. At traffic intersection locations, the concentration of OD_{2.6} varied from a minimum of nil at TIG0 location to a maximum of 8.9% at TIB0 location. The concentration of OD_{1.77} at H and IN locations was 1.4% and 4.0% respectively. The concentration of OD_{2.6} at IE locations was 11.0% while it was 5.4% at A0 location. It was obvious from above discussions that the concentration of OD_{0.88} and OD_{1.77} was comparatively higher than OD_{0.44} and OD_{2.6} and these were the dominant size groups. No definite trends for fine OD concentrations of various size groups at control and traffic activity related locations could be observed, as there were only slight variations.

The average values for cumulative OD_{2.5}, OD₅, and OD_{>5} are given in Table 4.34. The relative abundance of cumulative OD_{2.5} at CB locations was 96.0% in comparison to 92.7%, 93.3%, 93.0% and 93.6% at MP, MU, HP and HU locations respectively. Thus a slight decrease in cumulative OD_{2.5} concentrations was

Table 4.34 Distribution of oil-drops of other size groups in Shillong (% relative abundance)								
S No	Location	Cum. OD _{2.5}		OD ₅		OD _{>5}		Sample Size
		Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
1	CB	96.0 ±0.4	96.4	3.7 ±0.7	4.5	0.3 ±0.3	0.5	6
2	MP	92.7 ±4.0	97.7	6.5 ±4.4	17.1	0.7 ±1.2	4.2	31
3	MU	93.3 ±5.9	100.0	6.1 ±4.3	13.9	1.1 ±1.7	5.6	27
4	HP	93.0 ±7.8	100.0	4.3 ±2.9	9.6	2.7 ±6.5	24.0	35
5	HU	93.6 ±4.8	99.3	5.6 ±5.0	18.6	0.8 ±1.3	4.2	26
6	TIF0	99.0 ±1.4	100.0	1.0 ±1.4	4.4	0.0 ±0.0	0.0	2
7	TIB0	99.2 ±1.1	100.0	0.8 ±1.1	1.5	0.0 ±0.0	0.0	2
8	TIG0	100.0 ±0.0	100.0	0.0 ±0.0	0.0	0.0 ±0.0	0.0	2
9	H	95.8 ±3.8	98.5	2.1 ±0.9	2.8	2.1 ±2.9	4.2	4
10	IN	96.1 ±4.1	99.0	3.5 ±3.5	6.00	0.4 ±0.6	0.9	4
11	IE	94.9 ±7.3	100.0	4.8 ±6.8	9.6	0.5 ±0.6	0.9	4
12	A0	99.0 ±1.4	100.0	1.0 ±1.4	2.0	0.0 ±0.0	0.0	2

recorded at MP, MU, HP and HU locations. Concentration of cumulative OD_{2.5} at TIF0, TIB0 and TIG0 was 99.0%, 99.2% and 100.0% respectively. The concentration of cumulative OD_{2.5} at H and IN locations was 95.8% and 96.1% respectively. The concentration of cumulative OD_{2.5} at IE locations was 94.9% while it was 99.0% at A0 location. An increasing trend in concentration of cumulative OD_{2.5} could be observed at traffic intersections though we had observed minor

decreasing trends at MP, MU, HP and HU locations. There might be two reasons for such observations. One reason might be that observations at traffic intersections were made for only single location whereas the observations for MP, MU, HP and HU locations were the average of several locations. Another reason might be that traffic intersections had comparatively more pine vegetation around than MP, MU, HP and HU locations, which were considered as the major source of the oil-drop build up. The concentration of OD_5 was low ranging from 0.0% at TIG0 to 6.5% at MP locations. Like OD_5 , the concentration of $OD_{>5}$ was also very low as it ranged from 0.0% at TIF0, TIB0, TIG0 and A0 to 2.7% at HP locations.

4.5.9 Temporal variations in oil-drop size distributions

The temporal variations in relative abundance of $OD_{2.5}$ at CB locations (Table A.4.30) showed that the concentration of $OD_{0.44}$ ranged from 0.9% at CB1 to 11.8% at CB3. $OD_{0.88}$ concentration ranged from 49.9% at CB1 to 52.8% at CB2. Lowest concentration of 25.0% for $OD_{1.77}$ was obtained at CB3 while the highest of 34.9% was found at CB1. Similarly, the concentration of $OD_{2.6}$ ranged from 6.9% at CB3 to 9.9% at CB1. We observed that the concentration of $OD_{0.88}$ and $OD_{1.77}$ was higher in comparison with the OD of other size groups. It was conjectured at Chapter-3 that the sources of these OD might be pine trees. It appeared that these OD were released in the form of fine sprays but fast attained the size of $OD_{0.88}$ and $OD_{1.77}$ perhaps by coagulation process.

The temporal variations in relative abundance of OD of other size groups (Table A.4.31) depicted that the concentration of cumulative $OD_{2.5}$ ranged from

95.5% at CB1 to 96.4% at CB2. As such, the variations in OD_{2.5} concentrations among CB locations were not very substantial. The concentration of OD₅ ranged from 3.2% at CB2 to 4.5% at CB1. The concentration of OD_{>5} was almost insignificant with the maximum concentration of 0.5% at CB2. As such, we observed that the concentration of OD_{2.5} was quite significant due to its high concentrations.

The temporal variations in relative abundance of OD_{2.5} at MP locations (Table A.4.32) indicated that concentration of OD_{0.44} at MP locations ranged from 0.0% at MP1, MP2, MP10 and MP11 to 7.5% at MP3. Concentration of OD_{0.88} ranged from 29.0% at MP6 to 66.8% at MP3. The lowest concentration of 16.5% for OD_{1.77} was obtained at MP3 while the highest of 49.9% was found at MP9. Concentration of OD_{2.6} ranged from 1.8% at MP5 to 15.5% at MP7.

The temporal variations in relative abundance of OD of other size groups at MP locations (Table A.4.33) that concentration of cumulative OD_{2.5} ranged from 83.0% at MP10 to 97.7% at MP4. The concentration of OD₅ ranged from 2.0% at MP3 to 17.1% at MP10. Concentration of OD_{>5} ranged from 0.0% at MP1, MP2, MP3, MP4, MP5, MP10, MP11 and MP12 to 4.2% at MP13. The increase in maximum concentration of cumulative OD_{2.5}, OD₅ and OD_{>5} at certain MP locations was observed that appeared to be due to traffic activities.

The temporal variations in relative abundance of OD_{2.5} at MU locations (Table A.4.34) indicated that OD_{0.44} concentration ranged from 0.0% at MU3, MU5, MU6, MU8 and MU9 to 13.6% at MU2. OD_{0.88} concentration ranged from 27.1% at MU6 to 62.1% at MU4. Lowest concentration of 21.2% for OD_{1.77} was obtained at

MU5 while the highest of 52.8% was found at MU6. $OD_{2.6}$ concentration ranged from 3.2% at MU4 to 18.4% at MU9. A slight increase in maximum concentration of $OD_{1.77}$ and $OD_{2.6}$ at MU locations indicated that at steep gradient conditions the vehicles emitted OD corresponding to these size groups.

The temporal variations in relative abundance of oil-drops of other size groups at MU locations (Table A.4.35) showed that cumulative $OD_{2.5}$ concentration ranged from 80.6% at MU5 to 100.0% at MU8. Concentration of OD_5 ranged from 0.0% at MU8 to 13.9% at MU5. $OD_{>5}$ concentration ranged from 0.0% at MU1, MU2, MU3, MU4, MU8 and MU11 to 5.6% at MU5.

The temporal variations in relative abundance of $OD_{2.5}$ at HP locations (Table A.4.36) indicated that $OD_{0.44}$ concentration ranged from 0.0% at HP4 and HP12 to 28.0% at HP1. The variations in $OD_{0.44}$ concentrations at various HP locations were quite high. $OD_{0.88}$ concentration ranged from 32.5% at HP10 to 50.3% at HP3. Lowest concentration of 13.2% for $OD_{1.77}$ was obtained at HP1 while the highest of 58.3% was at HP11. $OD_{2.6}$ concentration ranged from 2.3% at HP11 to 14.0% at HP10.

The temporal variations in relative abundance of OD of other size groups at HP locations (Table A.4.37) showed that cumulative $OD_{2.5}$ concentration ranged from 70.4% at HP9 to 100.0% at HP6 and HP7. OD_5 concentration ranged from 0.0% at HP6 and HP7 to 9.8% at HP5. Concentration of $OD_{>5}$ ranged from 0.0% at HP3, HP4, HP6, HP7, HP11, HP12 and HP13 to 24.0% at HP9. The HP9 location, where the high concentration of $OD_{>5}$ was observed had been a busiest traffic activity location with highest number of two wheels vehicles. The location was

prone to the frequent road jams thus vehicles required high idle accelerations. Perhaps at accelerated conditions, vehicles emitted OD of OD_{>5} size group thus raising its concentration.

The temporal variations in relative abundance of OD_{2.5} at HU locations (Table A.4.38) indicated that OD_{0.44} concentration ranged from 0.0% at HU7, HU8, and HU10 to 8.0% at HU4. Concentration of OD_{0.88} ranged from 26.9% at HU6 to 61.5% at HU9. Lowest concentration of 31.0% for OD_{1.77} was obtained at HU9 while the highest of 51.7% was found at HU11. OD_{2.6} concentration ranged from 1.2% at HU5 to 17.9% at HU3.

The temporal variations in relative abundance of OD of other size groups at HU locations (Table A.4.39) showed that concentration of cumulative OD_{2.5} ranged from 81.4% at HU8 to 99.3% at HU9. Concentration of OD₅ ranged from 0.7% at HU9 to 18.6% at HU8. OD_{>5} concentration ranged from 0.0% at HU1, HU2, HU3, HU8, HU9 and HU11 to 4.2% at HU10.

The temporal variations in relative abundance of OD_{2.5} at TIF locations (Table A.4.40) indicated that highest concentration of 6.8% for OD_{0.44} was observed at TIFS1. A gradual decrease in OD_{0.44} concentration was observed at locations in south direction while in north direction it gradually decreased to 0.0% up to TIFN2 and again increased to 1.3% at TIFN3. The concentration of OD_{0.88} was 62.1% at TIF0. It showed a gradual decrease in north direction and the lowest value of 54.7% was recorded at TIFN3 while in south direction the concentration first dropped at TIFS1 and then increased to 76.5% at TIFS3. This increase is quite significant, as TIFS3 was located just adjacent to a forest having mostly pine trees. The assumption

that fine OD were emitted from pine trees appeared to be justified in view of the non-existence of any other viable source of OD. No definite pattern was observed for OD_{1.77}. Lowest OD_{1.77} concentration of 12.0% was observed at TIFS1 while the highest 21.4% was recorded at TIFN2. Like OD_{1.77}, OD_{2.6} also did not show any patterns. The concentration of OD_{2.6} ranged from 0.9% at TIFN3 to 9.7% at TIFN2.

The temporal variations in relative abundance of OD of other size groups at TIF locations (Table A.4.41) indicated that the concentration of cumulative OD_{2.5} was highest at TIF0 (about 99%). It gradually decreased in both north and south directions up to TIFN2 and TIFS2 and then again increased slightly at TIFN3 and TIFS3 where it was 94.7% and 98.4% respectively. The concentration of OD₅ was minimum at TIF0 (1.0%) while the highest of 9.2% was observed at TIFN2. In general, the concentration of OD₅ was more at across locations in comparison with the highway location. The lowest concentration of 0.0% of OD_{>5} was observed at TIF0 and in south direction while the highest concentration of 1.3% was observed at TIFN2.

The temporal variations in relative abundance of OD_{2.5} at TIB locations (Table A.4.42) showed that OD_{0.44} concentration was nil at TIB0 and locations in across directions. No definite patterns for OD_{0.88} concentration were observed. OD_{0.88} concentration was highest at TIBN3 where it was 54.9% while the lowest of 27.9% was obtained at TIBN1. Like OD_{0.88}, no definite patterns were observed for OD_{1.77}. OD_{1.77} concentration ranged from 35.4% at TIBS3 to 63.9% at TIBN1. OD_{2.6} concentration dropped at across locations from 8.9% at TIB0 to 3.6% and 4.4% at TIBN1 and TIBS1 respectively and again increased to 5.1% and 6.1% at TIBN3 and

TIBS3 respectively.

The temporal variations in relative abundance of oil-drops of other size groups at TIB locations (Table A.4.43) indicated that concentration of cumulative $OD_{2.5}$ was 99.2% at TIB0, which gradually dropped to 93.2% at TIBS3 while in north direction first it dropped at TIBN1 to 95.4% and then increased to 99.6% at TIBN3. TIBN3 also had comparatively large number of pine trees around. OD_5 concentration did not show any patterns and it ranged from 0.4% at TIBN3 to 4.8% at TIBS3. $OD_{>5}$ concentration was nil at TIB0 and across.

The temporal variations in relative abundance of $OD_{2.5}$ at TIG locations (Table A.4.44) showed that $OD_{0.44}$ concentration ranged from 0.0% at TIG0, TIGN2, TIGN3 and TIGS2 to 2.6% at TIGS1. $OD_{0.88}$ concentration dropped gradually from 73.4% at TIG0 to 52.7% at TIGN3 and 52.3% at TIGS2 excluding the TIGS3 that showed an increase again (74.2%). Lowest $OD_{1.77}$ concentration of 22.7% was observed at TIGS1 while the highest 42.7% was recorded at TIGS2. The $OD_{2.6}$ concentration ranged from 0.0% at TIG0 to 5.6% at TIGN3.

The temporal variations in relative abundance of OD of other size groups at TIG locations (Table A.4.45) showed that cumulative $OD_{2.5}$ concentration ranged from 90.3% at TIGS1 to 100.0% at TIG0 and TIGN3. OD_5 concentration was highest at TIGS1 while insignificant at other locations. Likewise, the highest concentration of 2.2% for $OD_{>5}$ was observed at TIGS1 while insignificant at rest of the locations.

The temporal variations in relative abundance of $OD_{2.5}$ at H and IN locations (Table A.4.46) indicated that $OD_{0.44}$ concentration at H1, IN1, H2 and IN2 locations

was nil. Concentration $OD_{0.88}$ was 31.6% and 46.7% at H1 and IN1 and 65.3% and 58.3% at H2 and IN2 respectively. Two opposite trends were observed for $OD_{0.88}$. While $OD_{0.88}$ concentration increased from H1 to IN1, it decreased from H2 to IN2. As mentioned earlier, IN1 had closed environment and IN2 had comparatively open environment. It appeared that in closed indoor environment the OD concentrations remained high perhaps due to the non-dispersion and up to some extent, because of release of OD from house hold activities including wooden furniture, wooden floors and ceilings etc. Comparatively, dispersion seemed to be better in the shop and there were hardly any oil-drop releasing activities (R.C.C. building). $OD_{1.77}$ concentration was 58.7% and 41.0% at H1 and IN1 and 33.2% and 38.8% at H2 and IN2 respectively. The observations were contrary to what had been observed for $OD_{0.88}$ concentrations. Perhaps, the build up of $OD_{1.77}$ was more at IN1 due to coagulation of fine oil-drops and due to non-dispersion. $OD_{2.6}$ concentration was 2.8% and 6.1% at H1 and IN1 and 0.0% and 2.0% at H1 and IN2 respectively.

The temporal variations in relative abundance of OD of other size groups at H and IN locations (Table A.4.47) showed that concentration of cumulative $OD_{2.5}$ was 93.1% and 93.2% at H1 and IN1 and 98.5% and 99.0% at H2 and IN2 respectively. As such, there were no variations in cumulative $OD_{2.5}$ concentrations at outdoor and indoor environment. OD_5 concentration was 2.8% and 6.0% at H1 and IN1 and 1.5% and 1.0% at H2 and IN2 respectively while the concentration of $OD_{>5}$ was 4.2% and 0.9% at H1 and IN1 and nil at H2 and IN2 respectively.

The temporal variations in relative abundance of $OD_{2.5}$ at IE locations (Tables A.4.48) indicated that $OD_{0.44}$ concentration at IE1 and IE2 was 6.6% and

5.0%. OD_{0.88} concentration was 38.5% and 37.4%, concentration of OD_{1.77} was 35.6% and 44.7% and concentration of OD_{2.6} was 9.0% and 13.0% at IE1 and IE2 respectively. The concentration of OD_{0.44} and OD_{0.88} had been slightly higher at IE1 than at IE2.

The temporal variations in relative abundance of OD of other size groups at IE locations (Table A.4.49) showed that concentration of cumulative OD_{2.5} was 89.7% and 100.0%, while the concentration of OD₅ was 9.6% and 0.0% at IE1 and IE2 respectively. OD_{>5} concentration was 0.9% and nil at IE1 and IE2 respectively.

The temporal variations in relative abundance of OD_{2.5} at A locations (Table A.4.50) indicated that OD_{0.44} concentration was 3.2% at A0 and 23.5% and 1.1% at A4 and A5 while it was nil at A1, A2 and A3. The high concentration of OD_{0.44} at A4 appeared to be due to situation of a restaurant at this floor. OD_{0.88} concentration gradually dropped from 65.6% at A0 to 32.5% at A4 then it increased to 63.4% on A5. Contrary to observations made for OD_{0.44} and OD_{0.88}, the concentration of OD_{1.77} increased gradually to 24.9% at A0 to 45.9% at A3 and then dropped again to 29.4% at A5. Perhaps the fine oil-drops got coagulated and could rise only up to certain height. OD_{2.6} concentration did not show any patterns and its concentration varied from location to location. The lowest concentration of 1.6% for OD_{2.6} was observed at A4 while the highest of 11.9% was observed at A3.

The temporal variations in relative abundance of OD of other size groups at A locations (Table A.4.51) showed that cumulative OD_{2.5} concentration dropped from 99.0% at A0 to 91.0% at A1 then it gradually increased up to 98.0% at A5. OD₅ concentration varied from location to location and it ranged from 1.0% at A0 to

9.0% at A1. The concentration of $OD_{>5}$ was found to be nil at all the locations.

4.5.10 Relationship of oil-drops with traffic density

The major source of fine OD in Shillong appeared to be from vegetation sources possibly pine trees that grow abundantly in the region, as the concentration of OD of this size group had been generally high at locations falling in vicinity of forests/thick vegetation. Other contributing factors for fine OD build up in atmosphere were considered to be vehicular emissions and up to some extent domestic cooking, fuel burning activities etc. The relationships of OD with traffic density at MP, MU, HP and HU locations was examined for their possible associations by obtaining Pearson correlation coefficients and results were discussed herein.

The relationship of $OD_{0.44}$ with TW (Table 4.35) was moderately positive at MP locations while it was negative at MU, HP and HU locations thus showing a gradual change in association. $OD_{0.88}$ showed negative relationship with TW at MP and HP locations but it was positive at MU and HU locations. It appeared that at steep road conditions, TW emitted OD of this size group. The relationship of $OD_{1.77}$ with TW was negative at MP and MU locations and positive at HP and HU locations

Table 4.35 Pearson correlation coefficients between oil-drops and two wheel vehicles							
Location	$OD_{0.44}$	$OD_{0.88}$	$OD_{1.77}$	$OD_{2.6}$	Cum $OD_{2.5}$	OD_5	$OD_{>5}$
MP	0.31	-0.23	-0.14	0.58*	-0.04	-0.08	0.39
MU	-0.04	0.42	-0.11	-0.50	0.12	-0.18	-0.25
HP	-0.12	-0.28	0.07	-0.52	-0.45	-0.21	0.63*
HU	-0.82*	0.33	0.03	-0.21	-0.01	0.34	0.34

* Significant correlation ($P < 0.05$)

and with OD_{2.6}, it was positive and significant ($p < 0.05$) at MP and negative at MU, HP and HU locations. The relationship of cumulative OD_{2.5} with TW was positive but weak at MU locations and negative at MP, HP and HU locations. OD₅ showed negative relationships with TW at MP, MU and HP locations and moderately positive at HU locations whereas the relationship of OD_{>5} was moderately positive at MP and HU locations and strongly positive and significant ($p < 0.05$) at HP locations and negative at MU locations. As such, the relationships of OD with TW appeared to be more location specific.

The relationship of OD_{0.44} with LV (Table 4.36) was moderately positive at MP locations, positive but weak at MU and HU locations while it was negative at HU locations. Relationship of OD_{0.88} with LV was negative at MP and HP locations but positive at MU and HU locations. The relationship of OD_{1.77} with LV was positive but weak at MP and MU locations and negative at HP and HU locations. OD_{2.6} showed positive and significant ($p < 0.05$) relationship with LV at MP locations and negative relationships at MU, HP and HU locations. The relationship of cumulative OD_{2.5} with LV was positive but weak at MU locations and negative at MP, HP and HU locations. OD₅ showed positive relationships with LV at MP

Table 4.36 Pearson correlation coefficients between oil-drops and light vehicles							
Location	OD _{0.44}	OD _{0.88}	OD _{1.77}	OD _{2.6}	Cum OD _{2.5}	OD ₅	OD _{>5}
MP	0.35	-0.43	0.01	0.67*	-0.19	0.11	0.28
MU	0.03	0.20	0.10	-0.45	0.25	-0.27	-0.41
HP	0.14	-0.06	-0.18	-0.68*	-0.45	-0.25	0.65*
HU	-0.83*	0.45	-0.32	-0.11	-0.16	-0.13	-0.13

* Significant correlation ($P < 0.05$)

locations and negative at MU, HP and HU locations. Relationship of $OD_{>5}$ with LV was moderately positive at MP locations, highly positive and significant ($p < 0.05$) at HP locations and negative at MU and HU locations.

The relationship of $OD_{0.44}$ with HV (Table 4.37) was moderately positive at MP, MU, HP and HU locations signifying that finest size OD were contributed by HV at all locations. Contrary to the observations made above, the relationship of $OD_{0.88}$ with HV was positive at MP and HP locations and negative at MU and HU locations. It appeared that at steep road conditions, HV emitted comparatively less $OD_{0.88}$. The relationship of $OD_{1.77}$ with HV was moderately positive at MU locations and negative at MP, HP and HU locations. $OD_{2.6}$ showed negative relationships with HV at MP and HP locations and positive relationships at MU and HU locations. Relationship of cumulative $OD_{2.5}$ with HV was positive but weak at MP locations, moderately positive at MU locations and negative at HP and HU locations. OD_5 showed negative relationships with HV at MP, MU and HP locations and positive at HU locations. The relationship of $OD_{>5}$ with HV was moderately positive at MP and HP locations and negative at MU and HU locations.

Table 4.37 Pearson correlation coefficients between oil-drops and heavy vehicles							
Location	$OD_{0.44}$	$OD_{0.88}$	$OD_{1.77}$	$OD_{2.6}$	Cum $OD_{2.5}$	OD_5	$OD_{>5}$
MP	0.35	0.06	-0.14	-0.06	0.09	-0.18	0.23
MU	0.40	-0.49	0.41	0.37	0.46	-0.42	-0.52
HP	0.28	0.06	-0.43	-0.04	-0.30	-0.28	0.49
HU	0.16	-0.06	-0.33	0.39	-0.09	0.11	-0.09

* Significant correlation ($P < 0.05$)

The relationship of $OD_{0.44}$ with ρ_T (Table 4.38) was moderately positive at

MP locations, positive but weak at MU and HP locations and negative and significant ($p<0.05$) at HU locations. Relationship of $OD_{0.88}$ with ρ_T was negative at MP and HP locations but positive at MU and HU locations. The relationship of $OD_{1.77}$ with ρ_T was positive but weak at MU locations and negative at MP, HP and HU locations. $OD_{2.5}$ showed positive relationship with ρ_T at MP locations, negative relationships at MU and HU locations and negative and significant ($p<0.05$) at HP locations. Relationship of cumulative $OD_{2.5}$ with ρ_T was moderately positive at MU locations and negative at MP, HP and HU locations. OD_5 showed positive relationships with ρ_T at HU locations and negative at MP, MU and HP locations. Relationship of with $OD_{>5}$ ρ_T was moderately positive at MP locations, highly positive and significant ($p<0.05$) at HP locations and negative at MU and HU locations. As such, we observed that $OD_{0.44}$ could be associated with vehicular emissions at MP, MU and HU locations. The vehicles also contributed $OD_{0.88}$ at steep gradient of MU and HU. The strong associations of $OD_{>5}$ at HP location was suggestive of the coagulation of released oil-drops to this size group.

Table 4.38 Pearson correlation coefficients between oil-drops and total traffic density							
Location	$OD_{0.44}$	$OD_{0.88}$	$OD_{1.77}$	$OD_{2.6}$	Cum $OD_{2.5}$	OD_5	$OD_{>5}$
MP	0.46	-0.32	-0.07	0.55	-0.10	-0.02	0.36
MU	0.13	0.10	0.18	-0.35	0.36	-0.37	-0.53
HP	0.14	-0.08	-0.21	-0.59*	-0.47	-0.27	0.69*
HU	-0.84*	0.43	-0.32	-0.07	-0.15	0.15	-0.04

* Significant correlation ($P<0.05$)

4.6 CONCLUSIONS

The following conclusions have been drawn on the basis of the results

obtained for size distributions of solid particles, temporal variations in size distributions of solid particles, linear relationship of solid particles with traffic density, Principal Component Analysis of solid particles, relationship of solid particles with meteorological variables, particle size distribution analysis with image analysis system, scanning electron microscopy of solid particles, size distributions of oil-drops, temporal variations in size distributions of oil-drops and relationship of oil-drops with traffic density:

Solid particle size distributions

- The concentration of fine solid particles of $PM_{0.44}$ and $PM_{0.88}$ showed significant increase at traffic activity related locations and was highest at certain traffic intersections in comparison with the CB locations.
- The concentration of $PM_{1.77}$ also showed increase at traffic activity related locations. $PM_{1.77}$ concentrations were more at plain locations of MP and HP than steep gradient locations of MU and HU, which was indicative of the probable source as resuspended dust.
- The concentration of $PM_{0.44}$, $PM_{0.88}$ and $PM_{1.77}$ showed decrease from H locations at highways to IN locations. The decrease had been gradual from $PM_{0.44}$ to $PM_{1.77}$.
- Invariably, the concentration of cumulative $PM_{2.5}$ also showed significant increase at traffic activity related locations and was recorded as the highest at certain traffic intersections in comparison with the CB locations.
- The concentration of PM_5 and PM_{10} showed decrease at traffic activity related

locations and it was highest at certain traffic intersections in comparison with the CB locations while $PM_{>10}$ showed less variations and it was somewhat similar to the concentrations of CB locations. This decrease might be attributed to the dilution effect due to sudden increase in fine particles at these locations.

- The concentration of PM_5 , PM_{10} and $PM_{>10}$ showed increase from H locations to IN locations. The indoor were not been subjected to abrupt changes in particulate concentrations resulting in such differences.

Temporal variations in solid particle size distributions

- Examination of temporal variations in concentration of solid particles of various size groups revealed significant standard deviations among the sampling locations signifying substantial variations in solid particle concentrations. It meant that the build up of various size group particulates at a particular location was more site-specific and it not only depended on its topographical situation but also on the factors like traffic density and prevailing meteorological conditions.
- While the higher build up of $PM_{0.44}$ and $PM_{0.88}$ at traffic activity related locations could be directly linked to vehicular emissions, the build up of $PM_{1.77}$ and $PM_{2.6}$ could be linked to coagulation of fine particles accentuated by generally high humid conditions in Shillong.
- The difference in concentration of $PM_{0.44}$ and $PM_{0.88}$ at moderate traffic density locations of MP and MU was more than the HP and HU locations suggesting further the site-specific nature of locations but as the vehicular

emissions became higher, this factor became weak thus reducing the gaps in concentrations of particles of these size groups.

- The traffic intersection locations while registering increase in concentrations of $PM_{0.44}$ and $PM_{0.88}$ and showing random drop in concentrations across locations did not depict the pattern of gradual drop that again suggested the site-specific nature of the locations and influence of meteorological factors.
- The comparatively less concentrations of $PM_{0.44}$, $PM_{0.88}$, $PM_{1.77}$ and $PM_{2.6}$ at IN locations was indicative of that penetration of fine particles in close vicinity of highways was not that pronounced. This might be attributed to the fact that the samplings were performed during the winters when people generally keep the indoor closed for keeping their houses warm.
- The significant variations in concentration of $PM_{0.44}$ and $PM_{0.88}$ at IE locations also signified the site-specific nature as vehicular emissions influenced one of the locations.
- The vertical movement of $PM_{0.44}$ and $PM_{0.88}$ up to the height of 17 meters could be established. This became significant because of the high number of residential buildings along the highways within the city confines.
- The concentrations of PM_5 , PM_{10} and $PM_{>10}$ had been influenced more by the natural factors (mostly for PM_5 as pollens, spores and other biogenic particulates that belong to this size group). The fact that concentration of these particulates became higher at locations away from traffic activity areas strengthens the assumption.

Relationship of solid particles with traffic density

- The least square linear regression plots drawn between solid particle concentrations and traffic density and Pearson correlation coefficients further established that the higher build up of $PM_{0.44}$ and $PM_{0.88}$ at MP, MU, HP and HU locations was due to vehicular exhaust emissions.
- Heavy vehicles were the highest contributor of $PM_{0.44}$ and $PM_{0.88}$ build up at MP, MU, HP and HU locations followed by light vehicles and two wheelers.
- Linear regression plots established the source of $PM_{1.77}$, $PM_{2.6}$, PM_5 , PM_{10} and $PM_{>10}$ other than vehicular emissions. While the build up of $PM_{1.77}$ and $PM_{2.6}$ could be linked to coagulation of fine particles and resuspension of dust, the PM_5 , PM_{10} and $PM_{>10}$ could be linked fairly to natural sources.

Source apportionment of solid particles with factor analysis technique

- Considering the factors with Eigen values above unity, vehicular emissions and resuspended dust were the two influencing factors at plain locations accounting for 83% and 73% for the solid particles build up at MP and HP locations respectively.
- The vehicular emissions, resuspended dust and gas-particle conversion and coagulation were the three influencing factors at uphill locations accounting for 89% and 84% for the solid particles build up at MU and HU locations respectively considering only the factors with Eigen values above unity.
- The 5-factor model was found to be quite suitable as it accounted for almost 100% for solid particle build up in breathing level atmosphere of Shillong.

Relationship of solid particles with meteorological variables

- The relationships of solid particles and meteorological variables established the site-specific nature of the locations as the sudden rise in particle concentrations was also influenced by factors like coagulation. In general, the relationships between solid particles concentrations and meteorological variables were not very strong.
- The relationships of temperature and solid particle concentrations had been highly varying for fine particles but the positive relationships with coarse particles of $PM_{>10}$ suggested that temperature assist in keeping these particle airborne for considerable period of time.
- Humidity also had varying relationships with solid particles but inverse relationships with fine particles had obviously demonstrated that high humidity reduced the concentration of this size group particle by way of facilitating coagulation.
- The rise in fine particle concentrations at across locations of traffic intersections might be due to high wind speeds. High wind speeds also assisted the build up of coarse particles concentrations at all locations.
- The wind direction assisted the build up of fine particle concentrations at most of the locations. It was due to frequently occurring direction changes, which helped in horizontal mixing of the solid particles.

Solid particle size distributions with image analysis system

- The measurement of solid particle size distributions by IAS and optical microscopy established that latter could be used for particle size determination with comparable precision and accuracy.
- IAS was found to be very useful in obtaining additional information like particle's length, breadth, area, perimeter and roundness, which could be used for further understanding of particle's physical properties. The digital images could be useful in identification of the source of the airborne particles.

Solid particle morphology with scanning electron microscope

- SEM provided useful information about individual particle's morphology and textural structure. It also provided the information regarding the particle's composition according to its shape and texture and helped in identifying its source.
- The prevalence of crustal and biogenic particles at CB locations and crustal particles with embedded small particles, porous and fluffy soot particles, conglomerates with concentric circular structure of discontinuous fringes and inter planer spacing at traffic activity related locations could be explicitly observed by SEM.
- The morphology of diesel and petrol particulates revealed that these particles were fluffy in nature in case of diesel particles and compact in case of petrol particles. The behaviour of these particles after inhalation appeared to be of interest due to their morphological structures and prevalence at breathing level

in Shillong.

Oil-drop size distributions

- The $OD_{0.88}$ and $OD_{1.77}$ were the most prevailing and dominant size of oil-drops among all the size groups implying that fine oil-drops fast attained these sizes by coagulation process and remained airborne for comparatively longer period of time.
- Barring a few locations, the concentration of $OD_{0.88}$ and $OD_{1.77}$ had been high at control locations establishing further the source as biogenic in origin. The release of terpenes by pine trees is a well-known phenomenon. It was not unlikely that the build of $OD_{0.88}$ and $OD_{1.77}$ concentrations at CB locations was due to abundance of pine trees and other vegetations.
- Almost all oil-drops belonged to the size group of cumulative $OD_{2.5}$ and thus were liable to be inhaled and lodged deep into the human respiratory system.
- The insignificant concentration of OD_5 and $OD_{>5}$ implied that oil-drops of these size groups did not remain airborne for substantial period of time and get scavenged from the atmosphere perhaps through embedding of solid particles and then settling due to gravity because of their heavier mass.

Temporal variations in oil-drop size distributions

- Similar to the observations made for solid particles, examination of temporal variations in concentration of oil-drops of various sizes revealed significant standard deviations among the sampling locations signifying substantial variations in oil-drop concentrations. It meant that the build up of oil-drops of

various size groups at a particular location was more site-specific and it not only depended on its topographical situation but also on the factors like vegetation cover, up to some extent the traffic density and prevailing meteorological conditions.

- While the higher build up of the concentrations of $OD_{0.44}$ at traffic activity related locations could be directly linked to the vehicular emissions, the build up of $OD_{0.88}$ and $OD_{1.77}$ could be linked to coagulation of fine oil-drops released from pine trees/vegetation.
- Rise in concentration of $OD_{0.88}$ and $OD_{1.77}$ at traffic activity related locations could be linked with vehicular emissions with a bias towards these size groups at steep gradient locations of MU and HU.
- In general, the concentrations of $OD_{0.88}$ and $OD_{1.77}$ increased at across locations of traffic intersections. The random decrease/increase in concentrations across the directions was indicative of site-specific nature of the locations as per the type and thickness of vegetation cover and influence of meteorological factors.
- The comparatively higher concentrations of $OD_{0.88}$ in close indoor environment of the house pointed at least the three likely sources/phenomena of i) comparatively less dispersion ii) house hold activities and iii) wooden furniture, floor, ceilings etc.
- The slight variations in concentration of $OD_{0.44}$ and $OD_{0.88}$ at industrial sites were due to proximity of one of the industrial location to pine forest.
- The $OD_{0.44}$ released at ground level got coagulated to $OD_{0.88}$ and moved

vertically with further simultaneous coagulation leading to formation of OD_{1.77}. Any further increase in size led to scavenging of oil-drops in the atmosphere.

Relationship of oil-drops with traffic density

- The Pearson correlation coefficients further established that the build up of OD_{0.44} at traffic activity related locations was due to vehicular exhaust emissions. Interestingly this build up was more due to heavy vehicles followed by light vehicles and two wheelers as evinced from correlation analysis
- Heavy vehicles were the highest contributors of OD_{0.88} build up at MU and HU locations indicating the bias of these vehicles to emit oil-drops of this size group at steep gradient conditions.
- The correlations of OD_{1.77}, OD_{2.6}, OD₅ and OD_{>.5} with traffic density was random and not that significant.

CHAPTER 5

CHAPTER 5

CHARACTERIZATION OF ELEMENTS IN SUSPENDED PARTICULATES

5.1 INTRODUCTION

One of the numerous geochemical features of urban atmosphere is that it acts as a spatial domain where a steady flow of incoming trace elements is received. Some of these elements and their compounds are considered very insidious pollutants because these are usually not biologically degradable and are liable to cause negative changes in humans, animals and plants even at quite low concentrations. The health implications of elemental inhalation have been subjected to intense research since the last several years and it is now obvious that children are the most susceptible sector of the population and at highest risks (Harvey *et al.*, 1985; McBride *et al.*, 1985). It was also established that children living in urban atmosphere had relatively higher concentrations of toxic metals like lead (Pb) and cadmium (Cd) in their blood (Cohen *et al.*, 1973; Waldran, 1975). Pb also affects several organs of the human body in adults including the nervous system, the blood forming system, the kidneys, the cardiovascular system, reproductive systems and it causes increased blood pressure and hypertension

increasing the risk of cardiovascular diseases. Apart from Pb and Cd, there are quite a few other elements of interest found in the atmosphere in ultratrace and trace amounts in the form of aerosols that are toxic in nature and cause serious health hazards. The more important among these are Nickel (Ni), Copper (Cu), Chromium (Cr), Zinc (Zn), Iron (Fe), Manganese (Mn) and Cobalt (Co). The higher concentration of these elements causes various ailments and some of them even act as carcinogens. There is a greater awareness now that the concentration of elements in urban atmosphere is steadily on the increase due to ever-increasing number of motor vehicles, development of industrial zones and housing complexes that cater to the modern population needs.

The particle size of toxic elements is also of fundamental importance as it governs their atmospheric residence time, serves as unique tracer of their source and determines their ability to penetrate the human respiratory tract. Potentially toxic elements have large proportions of particle size below $0.7\text{ }\mu\text{m}$ of diameters and could, therefore, pass and settle down directly into alveoli, the deepest part of the human respiratory system (McDonald. *et al.*, 1979b).

Thus, accounting for elemental concentrations in the suspended particulate matter has been the long-term objective in the investigations of atmospheric aerosols and, therefore, of utmost importance from the point of view of their hazard evaluation, source identification and in prevention of possible health hazards by adoption of timely requisite measures.

In the present work we have discussed various elemental analysis techniques, some experimental aspects and the results and discussion on the monitored

elements of Pb, Ni, Cu, Cd, Cr, Fe, Zn, Mn, Co, K, Mg and Na. The elemental analysis techniques have been discussed in section 5.2. Aspects on other experimental details have been described in section 5.3. Section 5.4 deals with the results and discussion which include discussion on elemental concentrations at various categories of locations, enrichment factor analysis of elements, pair-wise Pearson correlation coefficients of elements and factor analysis by employing Principal Component Analysis with Varimax rotation. The conclusions of this part of study are drawn in section 5.5.

5.2 TECHNIQUES OF ELEMENTAL ANALYSIS

A number of chemical and modern instrumental analytical techniques are in use to determine the elemental concentrations in suspended particulate matter. No matter how much air is drawn through a filter and despite occasionally high particle loadings in the atmosphere, the amount of sample available for chemical analysis is small. The typical mass loadings obtained with a low volume air sampler are less than 5 mg and many of the chemical species of interest must be measured when even less than 1 mg is present in the deposit. As such, instrumental methods are most suited for the purpose as number of elements of interest can be analyzed in a small particulate mass. Some other factors of consideration for arriving at a suitable analytical choice are i) the nature and chemical composition of the sample ii) nature of matrix and iii) precision and accuracy required. In analyzing various elemental concentrations of large number of aerosol samples for various elements within a short span of time, the selected analytical technique must be fast, accurate and with

high precision. Chow, (1995) has summarized various instrumental techniques for elemental analysis. These techniques include X-Ray Fluorescence (XRF), Proton Induced X-Ray Emission Spectroscopy (PIXE), Instrumental Neutron Activation Analysis (INAA), Inductively Coupled Plasma (ICP) Emission Spectroscopy and Atomic Absorption Spectrometry (AAS). The AAS technique has been used for determination of elemental concentrations in this study.

5.2.1 Atomic Absorption Spectroscopy

Atomic Absorption Spectroscopy (AAS) is a simple, rather cost effective and rapid analytical technique widely in use for determination of elements in aerosol samples (Cresser *et al.*, 1986; Langmyhr *et al.*, 1978; Ranweiler *et al.*, 1974; Rhodes, 1989). The instrument works on the principle of the Beer's Law that can be represented by the following equation:

$$A = \log I_0 / I_{tr} = k \cdot c \cdot d. \quad (5.1)$$

(where I_0 is intensity of incident light and I_{tr} is intensity of the transmitted light, k is constant, c is concentration of absorbing substance and d is thickness of the absorbing layer)

It states that the absorbance A (the logarithm of the reciprocal of transmission) is proportional to the concentration of the absorbing substance and to the thickness of the absorbing layer. The most important components of the AAS are a radiation source, which emits the spectrum of the analyte element, an atomizer, such as flame, in which the atoms of the sample to be analyzed are formed, a

monochromator for spectral dispersion of the radiation with an exit slit for selection of the resonance light; a detector permitting measurement of radiation intensity, followed by an amplifier and a readout device (Fig. 5.1). The radiation source is a hollow cathode lamp, the cathode of which is made up of the element to be analyzed. To eliminate the interference due to the flame emission, a chopped or pulsed radiation is now used, wherein the radiation from the primary source having the modulation frequency, is amplified while the emission from the flame, which is not modulated, is neglected (Welz, 1985). The sample to be measured is generally atomized in a flame supported by a fuel-oxidant mixture such as hydrogen and air or hydrogen and oxygen or acetylene and nitrous oxide or some other suitable mixture. Normally the flame is extended along the axis of the light beam to provide a long absorption path. The aerosol samples in solution form are aspirated into the flame, where evaporation of the solvent and analyte occur. Careful control of the temperature is needed for optimum conversion to the atomic vapor. Too high and low temperatures cause a fraction of the atoms to become ionized, and hence not to absorb at the expected wavelengths. The radiation from the source traverses the atomic population representing the sample, enters the entrance slit of the monochromator that separates the desired resonance line from the other lines that may be present. A photo multiplier tube and amplifier measure the net radiation intensity. Quantitative determination of the concentration of elements is done using appropriate calibration curves.

One of the main disadvantages of the AAS is that sample is destroyed during analysis and cannot be used for other analytical purposes. Loss in sensitivity and

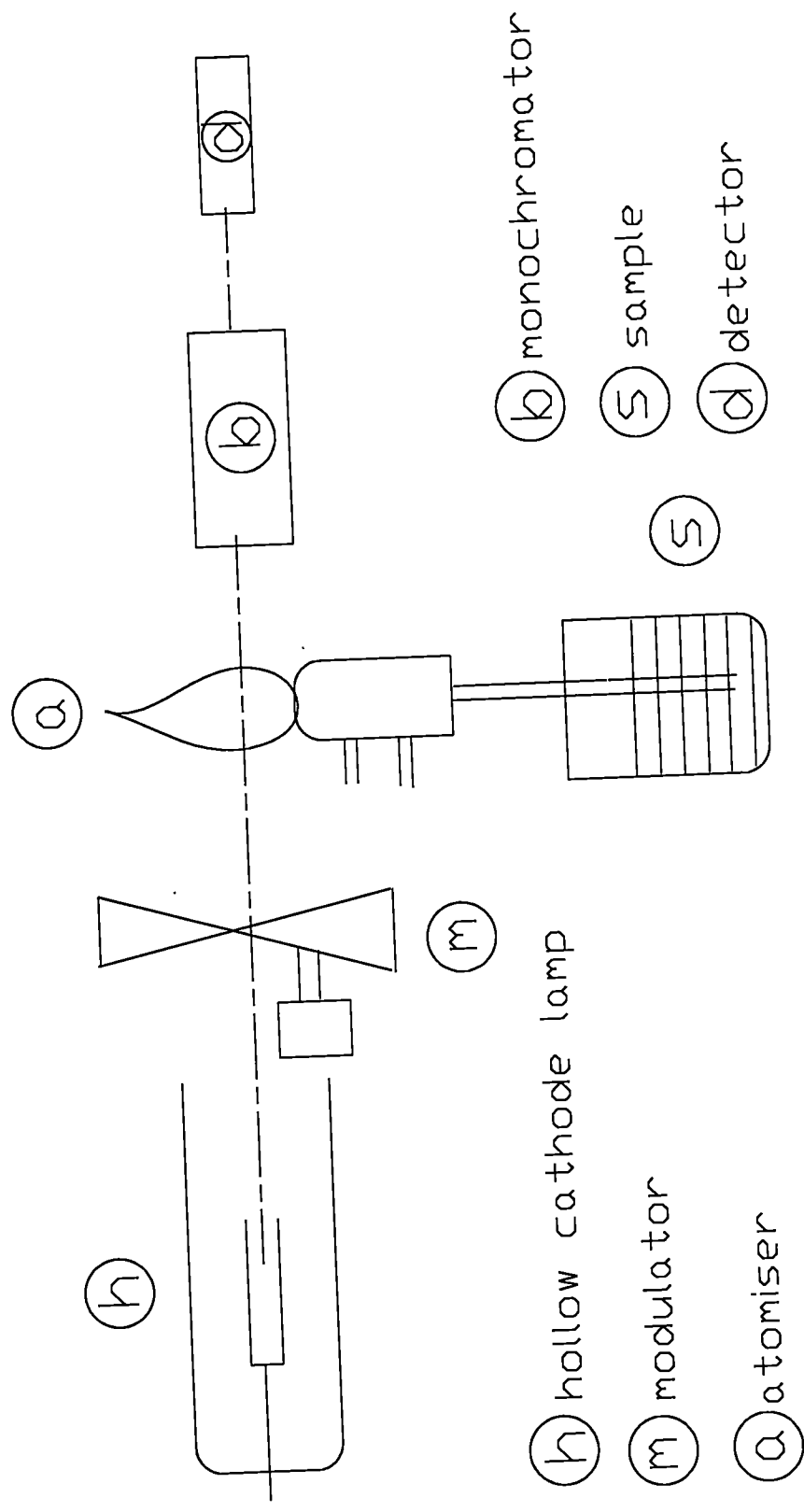


Fig. 5.1 Schematic diagram of atomic absorption spectrophotometer

accuracy caused by chemical interference during atomizing of solutions with high salt contents is another disadvantage.

5.3 EXPERIMENTAL ASPECTS

The experimental aspects cover details on preparation of elemental standards, preparation of aerosol samples for elemental analysis, preparation of standard curves, calibration with reference standards and determination of elements with AAS (Shimadzu 680G). The sensitivity, working range and detection limits of AAS for the elements of interest are given in Table 5.1.

Table 5.1 Sensitivity, working range and detection limits of atomic absorption spectrophotometer for elements			
Element	Sensitivity µg/ml	Range µg/ml	Detection Limits µg/ml
Pb	0.11	1-10	0.02
Ni	0.066	0.5-5.0	0.008
Cu	0.040	0.5-5.0	0.003
Cd	0.011	0.1-1.0	0.0006
Cr	0.055	0.5-5.0	0.005
Fe	0.062	0.5-5.0	0.005
Zn	0.009	0.1-1.0	0.002
Mn	0.026	0.5-5.0	0.003
Co	0.066	0.5-5.0	0.007
K	0.010	0.1-1.0	0.003
Mg	0.003	0.05-0.50	0.0003
Na	0.003	0.05-0.50	0.0003

5.3.1 Preparation of elemental standards

Stock solutions of elemental standards for Pb, Ni, Cu, Cd, Cr, Fe, Zn, Mn, Co, K, Mg and Na were prepared either using pure metals or their compounds (analytical grade) as per methods given in the Standard Methods for Air Sampling

and Analysis (APHA, 1977). The distilled water used for preparation of standards was of nanopure grade obtained with a Purelab Classic USA system (Model-D-56235). All of these stock solutions were made to a concentration of 1000 μg of element per ml and stored in polythene bottles for use.

5.3.2 Preparation of particulate samples for elemental analysis

The Particulate matter was carefully removed from the sample filter papers. A known weight of the sample was dissolved in 10 ml of conc. HNO_3 and the solution was then heated in a fume chamber to dryness. The contents were dissolved again in 10 ml of 20% HNO_3 . The prepared solution was then quantitatively filtered through a micro-filtration unit using nitro-cellulose membrane filters (Millipore) of 25 mm dia with pore size of $0.30\mu\text{m}$. The blank solutions were also prepared in the similar way. The sample filtrate and blank solutions were kept in volumetric flask (Cap 50 ml) and stored in a refrigerator for analysis. All reagents used were of analytical grade.

5.3.3 Determination of elemental concentrations

An atomic absorption spectrophotometer (Shimadzu-AA 680 G) was used for elemental analysis. The system had the wavelength range of 190~900 nm with high-speed dual-frequency synchronized photometric system with automatic gain control. Pulse modulating lighting (500 Hz) was used for HC lamp. Other automatic facilities included storage of all operational parameters like operation of lamp turret (8-lamp turret), beam combiner, needle valve, wavelength and slit width setting of

the monochromator and fuel flow rates. The working curves were determined by using least square methods to improve accuracy. Adoption of average values by effecting at least 10 repeated analyses and automatic elimination of abnormal values and recalculation were added features for accuracy improvement. The operating conditions for analysis of the each element are provided in Table 5.2. The standard working curves were prepared with the help of the standard solutions for each of the element making background corrections with the help of the blank solutions. The working curve prepared for iron is provided at Fig. 5.2. All calculations for determination of elements concentrations were carried out as per APHA (1977). The Standard Reference Material (SRM) 1643b from U.S. National Bureau of Standards was simultaneously used for evaluation of the analytical accuracy of elements. The results were found to be within $\pm 20\%$ of the certified values of the elements (Table 5.3).

Table 5.2 Operating conditions for elements with atomic absorption spectrophotometer						
Element	Wavelength (nm)	HC lamp Current (mA)	Slit Width (nm)	Type of Flame	Flue gas Flow Rate	% Abs. Conc.
Pb	217.0	7	0.3	Air-C ₂ H ₂	1.8	0.2
Ni	232.0	4	0.15	Air-C ₂ H ₂	1.7	0.1
Cu	324.8	3	0.5	Air-C ₂ H ₂	1.8	0.09
Cd	228.8	4	0.3	Air-C ₂ H ₂	1.8	0.02
Cr	357.9	5	0.5	Air-C ₂ H ₂	2.6	0.09
Fe	248.3	8	0.2	Air-C ₂ H ₂	2.0	0.1
Zn	213.9	4	0.5	Air-C ₂ H ₂	2.0	0.02
Mn	279.5	5	0.4	Air-C ₂ H ₂	1.9	0.05
Co	240.7	6	0.2	Air-C ₂ H ₂	2.2	0.2
K	766.5	5	0.5	Air-C ₂ H ₂	1.9	0.04
Mg	285.2	4	0.5	Air-C ₂ H ₂	1.6	0.007
Na	589.0	6	0.5	Air-C ₂ H ₂	1.6	0.02

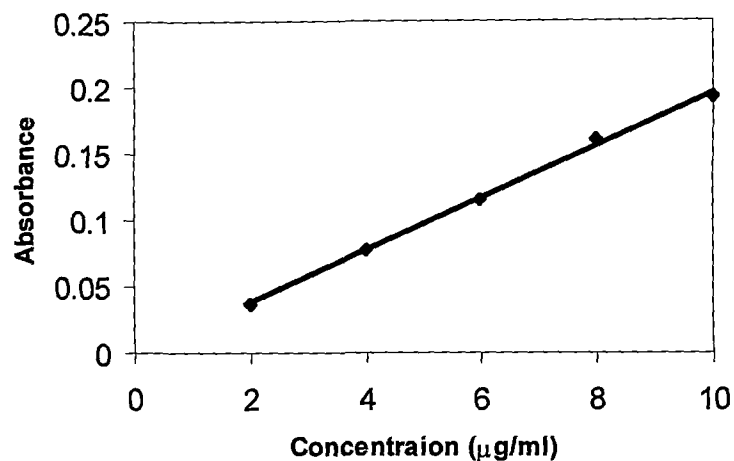


Fig. 5.2 Calibration curve for iron

Table 5.3 Accuracy evaluation of elements with atomic absorption spectrophotometer			
Element	Certified Conc. of Element in SRM (ng/ml)	Measured Conc. of Element in SRM (ng/ml)	Deviation (%)
Pb	24.1 ± 0.7	26.3	9.1
Ni	49.8 ± 3.1	58.0	17.7
Cu	22.3 ± 0.4	23.7	15.2
Cd	20.3 ± 1.0	24.1	18.7
Cr	18.9 ± 0.4	22.6	19.6
Fe	100.7 ± 8.1	96.5	4.2
Zn	67.1 ± 2.0	69.9	4.2
Mn	28.5 ± 2.0	33.4	17.2
Co	26.4 ± 1.0	29.2	10.6

5.4 RESULTS AND DISCUSSION

We have divided the results into 4 sub-sections. In sub-section 5.4.1, we have discussed the elemental concentrations obtained at classified categories and compared our results with that obtained by other workers for major cities of the world. In order to differentiate between anthropogenic and natural sources of

elemental build up, the Enrichment Factors analysis has been carried out and results are discussed at sub-section 5.4.2. The interrelationship of elements at classified categories has been established by obtaining Pearson correlation coefficients and the same are provided at sub-section 5.4.3. To acquire the number and nature of elemental sources, the element concentration values have also been subjected to factor analysis using Principal Component Analysis technique with Varimax rotation method and the results obtained in the form of new latent variables called principal components or factors are discussed in sub-section 5.4.4.

5.4.1 Elemental concentrations

The mean **Lead** (Pb) concentrations obtained at classified categories of monitored locations are provided at Table 5.4. Considerably high concentrations of Pb were observed even at the CB locations. A further gradual increase in mean Pb concentrations could be seen at MP, MU, HP and HU locations with uphill locations of MU and HU showing slightly higher concentrations in comparison with the plain locations of MP and HP. Since, Pb concentrations in ambient air could be directly linked with the vehicular emissions, it was possible that at steep gradient conditions, as existed at the uphill locations, the vehicles emitted more Pb. Our findings are comparable to the observance of Ledolter *et al.* (1979) who found increase in Pb concentrations from $7.91 \mu\text{gm}^{-3}$ to $10.87 \mu\text{gm}^{-3}$ with increasing traffic speed on highways. The generally high Pb concentrations at these locations of Shillong might also be due to the high Pb contents in petrol (about 0.56% to 0.96 % by mass) during the study periods and negligible number of motor vehicles meeting Euro-I or Euro-II

Table 5.4 Concentration of lead in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	0.52	0.54	0.03	3
MP	1.97	3.47	0.79	13
MU	2.32	7.86	2.03	11
HP	2.56	6.58	1.66	13
HU	2.78	7.43	1.66	11
TIF	0.60	0.85	0.16	7
TIB	0.85	1.16	0.16	7
TIG	0.85	1.08	0.14	7
H	1.09	1.20	0.16	2
IN	0.94	1.00	0.08	2
IE	1.35	1.46	0.15	2
A	0.63	0.85	0.14	5

norms. Sampling had been performed during the peak activity hours of 9 - 17 IST, which might be another factor for high Pb concentrations. Simmons *et al.* (1993) had earlier observed that the short rush hours airborne Pb concentrations for Bermuda Island would have been as high as 18-20 μgm^{-3} and, as such, was in agreement with our Pb observations. Comparing our results with that in other major cities of India as well as of the world (Table 5.5) we find that the Pb concentrations were low in comparison with those at North Florida, Leötvös, Ho Cho Minh city, Khartoum, Mumbai and Tiruchirapalli while were high at Bermuda Island, Riyadh and Moradabad. This indicated that build up of Pb concentrations at a particular location was site-specific in nature depending on factors such as petrol characteristics, status of vehicles with respect to emission control equipments, road gradients and width, traffic concentrations and composition, meteorological conditions and sampling timings. At a first glance, the mean Pb concentrations at traffic intersections were comparatively low. It was due to considering average of the Pb concentrations

Table. 5.5 Lead concentrations in various cities of the world (μgm^{-3})		
Location	Concentration	Reference
North Florida, U.S.A.	0.11	Johansson <i>et al.</i> , 1976
Leötvös, Hungary	0.20	Molnár <i>et al.</i> , 1993
Ho Cho Minh, Vietnam	0.20	Hien <i>et al.</i> , 1997
Bus Garage, Bermuda Island	5.50	Simmons <i>et al.</i> , 1993
Khartoum, Sudan	0.04	Eltayeb <i>et al.</i> , 1993
City Centre, Riyadh	4.09	Raoof, S.A. et al, 1992
Vikroli, Mumbai	0.68	Tripathi <i>et al.</i> , 1999
W.B.Road, Tiruchirapalli	1.14	Chandrasekeran <i>et al.</i> , 1997
Pheel Khana, Moradabad	14.40	Tripathi <i>et al.</i> , 1990

for across direction and highway locations together. As expected, a gradual drop in Pb concentrations was seen at across locations of all the traffic intersections (Tables A.5.1 to A.5.3) thus giving a clearer picture. Although the concentration of Pb was comparatively less at IN locations than the H locations, it was considerably high considering the low TSP values at IN environment. The Pb concentrations at IE locations were also high. It appeared to be due to proximity of one location to the highway because there had been hardly any industrial activity that could be associated with high Pb concentrations. The mean Pb concentration at A locations was comparatively low. Again, a gradual decrease in Pb concentrations was clearly evident from ground floor (A0) to the rooftop (A5) (Table. A.5.4).

The Indian Pb standard notified under NAAQS is $0.75 \mu\text{gm}^{-3}$ (24 hours average) for Sensitive Areas (Shillong falls under sensitive area due to its status as a major hill station). We classified the monitored sampling locations on the basis of Pb concentrations into low ($<0.5S$), moderate (between $0.5S$ to $1.0S$), high (between $1.0S$ to $1.5S$) and critical ($>1.5S$), where S is the 24 hours standard for Pb. While no location fell under “low” category, CB locations, across locations of TIF, TIBN2,

TIBN3, TIGN3 and all locations at various elevations excluding A0 were “moderate”, the “high” category locations were TIF0, TIB0, TIG0, H, IN, IE and A0. The locations of MP, MU, HP and HU fell under “critical” category. The Main *et al.* (1990) had observed the trimodal nature of the particle size distribution for Pb in ambient air with strongest being 2.0-4.0 μm ranges. Lyonos *et al.* (1993) also observed similar particle size ranges (0.075-0.26, 0.5-1.0 and 2-4 μm) for Pb and suggested that the last size group might be formed due to coagulation of smaller particles. As the concentration of cumulative $\text{PM}_{2.5}$ was high at breathing level in Shillong with high Pb contents, the health hazard of quite serious dimensions could not be ruled out.

The mean **Nickel** (Ni) concentrations are provided at Table 5.6. Excluding CB locations, Ni concentrations showed little variations as it ranged from 0.03-0.07 $\mu\text{g m}^{-3}$. Concentration of Ni was slightly higher at highway locations of traffic intersection but dropped in across directions (Tables A.5.1 to A.5.3). Likewise, a drop was also noticed with increasing vertical heights (Table. A.5.4). The airborne Ni was also considered as toxic with the major source as burning of residual fuel oils (Cass, 1983). Ni had also been detected in crude petroleum oil (Hofstader *et al.*, 1974). As the Ni concentrations were more at traffic activity related locations in Shillong, it undoubtedly indicated the source as vehicular emissions but non observance of high Ni build up might be due to its generally unimodal size distributions (below 0.5 μm) with no growth in 0.5-1.0 μm size range. Possibility of enrichment of Ni in soils becomes difficult due to its unimodal nature (Lyonos *et al.*, 1993). The Ni concentrations in Shillong were comparable with that obtained at

Table 5.6 Concentration of nickel in TSP at various locations in Shillong ($\mu\text{g m}^{-3}$)				
Location	Mean	Max	SD	Sample Size (N)
CB	0.01	0.01	0.00	3
MP	0.04	0.09	0.03	13
MU	0.04	0.08	0.02	11
HP	0.04	0.09	0.03	13
HU	0.05	0.08	0.02	11
TIF	0.04	0.06	0.02	7
TIB	0.03	0.05	0.01	7
TIG	0.04	0.10	0.03	7
H	0.07	0.07	0.00	2
IN	0.04	0.04	0.00	2
IE	0.03	0.06	0.02	5
A	0.03	0.06	0.02	5

Table 5.7 Nickel concentrations in various cities of the world ($\mu\text{g m}^{-3}$)		
Location	Concentration	Reference
Leötvös, Hungary	0.006	Molnár <i>et al.</i> , 1993
Kuwait	0.08	Raveendran <i>et al.</i> , 1992
Khartoum, Sudan	0.009	Eltayeb <i>et al.</i> , 1993
City Centre, Riyadh	0.04	Raoof <i>et al.</i> , 1992

Kuwait and Riyadh but quite high in comparison with that in Leötvös and Khartoum (Table 5.7).

The mean **Copper** (Cu) concentrations (Table 5.8) were less at MP, MU and HU locations in comparison with CB locations with the ratio of 0.7, 0.8 and 0.8 respectively while the concentrations were same at HP locations. Mobile sources, industrial processes and crustal material are considered to be the sources of airborne copper (Cass, 1983). The former two sources were ruled out for CB locations due to non-existence of these activities. Moreover, the Cu concentrations would have increased at MP, MU, HP and HU locations if the sources were mobile ones or

industrial processes. Since the concentration of Cu at traffic intersections, IN and IE showed little variations, the source could be the crustal materials. The Cu concentrations in other cities of the world were low in comparison with Shillong except in Riyadh where it had been above $1.0\mu\text{gm}^{-3}$ whereas, its concentrations in Indian cities were high (Table 5.9). We observed the highest Cu concentrations at highways, which were about 1.5 times of the concentrations at CB locations. Occasional slight increase in Cu concentrations at some locations appeared to be due to resuspended dust.

Table 5.8 Concentration of copper in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	0.42	0.45	0.04	3
MP	0.30	0.42	0.08	13
MU	0.34	0.58	0.12	11
HP	0.42	0.98	0.22	13
HU	0.35	0.63	0.15	11
TIF	0.44	0.69	0.15	7
TIB	0.50	0.65	0.10	7
TIG	0.50	0.63	0.09	7
H	0.60	0.64	0.06	2
IN	0.49	0.54	0.07	2
IE	0.46	0.49	0.05	2
A	0.49	0.62	0.09	5

Table 5.9 Copper concentrations in various cities of the world (μgm^{-3})		
Location	Concentration	Reference
Leötvös, Hungry	0.02	Molnár <i>et al.</i> , 1993
Khartoum, Sudan	0.004	Eltayeb <i>et al.</i> , 1993
City Centre, Riyadh	1.01	Raoof <i>et al.</i> , 1992
Kuwait	0.01	Raveendran <i>et al.</i> , 1992
Vikroli, Mumbai	0.20	Tripathi <i>et al.</i> , 1999
BHU, Varanasi	2.06	Tripathy <i>et al.</i> , 1995
Pheel Khana, Moradabad	6.50	Tripathi <i>et al.</i> , 1990

The mean **Cadmium** (Cd) concentrations are provided at Table 5.10. The concentration of Cd increased for about 2 times at MP, MU, HP and HU locations in comparison with CB locations. The concentration of Cd was also about 2 times higher at TIF0. Gradual drop in Cd concentrations at across locations of TIF (excluding TIFS3) was observed (Tables A.5.1 to A.5.3). The concentration of Cd had been slightly less at IN than H locations. Cd concentration was low at IE locations but showed an upward trend at A locations showing increase with increasing height. We had observed earlier (Chapter-4.5.1) that cumulative PM_{2.5} concentrations were quite high at breathing levels. It appeared that the particle size of Cd belonged to PM_{2.5} size group thus showing the increase in Cd concentrations. The source of Cd appeared to be bimodal in nature due to its very high concentrations. One of the sources of Cd invariably was the exhaust emission as it had been observed in the crude petroleum oil (Hofstader *et al.*, 1974). Our findings

Table 5.10 Concentration of cadmium in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	0.05	0.07	0.02	3
MP	0.09	0.16	0.03	13
MU	0.12	0.57	0.16	11
HP	0.11	0.37	0.08	13
HU	0.10	0.17	0.06	11
TIF	0.12	0.20	0.06	7
TIB	0.02	0.08	0.03	7
TIG	0.05	0.07	0.03	7
H	0.19	0.23	0.05	2
IN	0.16	0.17	0.01	2
IE	0.06	0.07	0.02	2
A	0.20	0.22	0.02	5

of Cd concentrations in Shillong were comparatively higher than that observed at Kuwait and Moradabad but were quite comparable to those at Mumbai (Table 5.11).

Table 5.11 Cadmium concentrations in various cities of the world (μgm^{-3})		
Location	Concentration	Reference
Kuwait	0.002	Raveendran <i>et al.</i> , 1992
Vikroli, Mumbai	0.18	Tripathi <i>et al.</i> , 1999
Pheel Khana, Moradabad	0.07	Tripathi <i>et al.</i> , 1990

The mean **Chromium** (Cr) concentrations (Table 5.12) increased from CB locations to MP, MU, HP and HU locations. The increase had been from 2.0-3.5 times but as such no trends were observed. Concentration of Cr was low at TIB0 and TIG0 but similar to as was observed at CB locations. It was about 3 times at TIF0. A gradual drop in Cr concentration was observed at across locations of traffic intersections (Tables A.5.1 to A.5.3). Cr concentration had slightly dropped from H to IN locations. Concentration of Cr increased by 3 times at IE locations in comparison with CB locations. Cr concentrations showed a gradual decrease with increasing heights (Table A.5.4). Cr had also been detected in trace concentrations in crude petroleum oil (Hofstader *et al.*, 1974). The source of Cr in Shillong appeared to be the vehicular exhausts as its concentration generally increased at traffic activity related locations. Moreover, there had been no known industrial source contributing to airborne Cr concentrations. Our findings of Cr concentrations were comparable with cities of Leötvös and Kuwait but were comparatively higher in comparison with Khartoum and Glasgow. This perhaps indicated higher Cr concentrations in petroleum products that were used in Shillong (Table 5.13).

Table 5.12 Concentration of chromium in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	0.02	0.03	0.01	3
MP	0.05	0.11	0.03	13
MU	0.07	0.15	0.04	11
HP	0.06	0.15	0.04	13
HU	0.04	0.11	0.03	11
TIF	0.06	0.09	0.02	7
TIB	0.02	0.05	0.01	7
TIG	0.03	0.04	0.01	7
H	0.02	0.03	0.00	2
IN	0.01	0.01	0.00	2
IE	0.06	0.07	0.02	2
A	0.01	0.03	0.01	5

Table 5.13 Chromium concentrations in various cities of the world (μgm^{-3})		
Location	Concentration	Reference
Leötvös, Hungry	0.01	Molnár <i>et al.</i> , 1993
Kuwait	0.02	Raveendran <i>et al.</i> , 1992
Khartoum, Sudan	0.008	Eltayeb <i>et al.</i> , 1993
Glasgow	0.008	McDonald <i>et al.</i> , 1979a

As expected, the mean **Iron (Fe)** concentrations (Table 5.14) increased at all categories of monitored locations in comparison with CB locations. The increase was about 2 to 4 times at MP, MU, HP and HU locations but less at TIF and TIB. Gradual drop in Fe concentrations was witnessed at across locations of TIF but not at the TIB and TIG intersections. In fact, very low Fe concentrations were observed at TIB and it's across locations in the both directions (Tables A.5.1 to A.5.3). The TIB location was comparatively better ventilated than other intersection locations due to its open surroundings. The drop in Fe concentrations at IN locations was also on expected lines. Concentration of Fe increased to about 4 times at IE locations in

Table 5.14 Concentration of iron in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	4.71	6.27	1.37	3
MP	10.76	25.26	5.97	13
MU	10.53	24.75	7.06	11
HP	11.14	20.91	4.76	13
HU	16.61	35.20	9.34	11
TIF	8.20	16.13	3.90	7
TIB	5.52	7.43	1.48	7
TIG	9.11	12.70	3.82	7
H	10.84	13.97	4.43	2
IN	8.88	12.45	5.05	2
IE	15.29	22.90	10.76	2
A	12.56	16.13	2.51	5

comparison with CB locations. Gradual drop in Fe concentrations with increasing heights was also observed at A locations (Table A.5.4). The main source of Fe had been attributed to the resuspension of dust and other forms of the crustal materials (Davidson, 1986). As such, it is often used as tracer for crustal material for source apportionment studies. Even up to 94% of Fe concentrations had been accounted from crustal source (Cass, 1983). The dominance of crustal source for Fe was supported by its size distributions measured by Lundgren, (1971). Lyonos *et al.* (1993) further proved that the Fe size distributions were unimodal in nature and were of 2-4 μm range that further established the source being suspended dust. The increase in Fe concentrations at anthropogenic activity associated locations and drop in its concentrations with increasing heights in our study also inferred the source as being the suspended dust. Fe concentrations obtained by us were comparable with cities of Khartoum, Riyadh and Tiruchirapalli but were comparatively less in

Table 5.15 Iron concentrations in various cities of the world (μgm^{-3})		
Location	Concentration	Reference
Leötvös, Hungry	0.72	Molnár <i>et al.</i> , 1993
Khartoum, Sudan	5.30	Eltayeb <i>et al.</i> , 1993
City Centre, Riyadh	11.61	Raoof <i>et al.</i> , 1992
Kuwait	0.60	Raveendran <i>et al.</i> , 1992
W.B.Road, Tiruchirapalli	6.97	Chandrasekeran <i>et al.</i> , 1997

comparison with Leötvös and Kuwait (Table 5.15)

The mean **Zinc** (Zn) concentrations (Table 5.16) decreased at all categories of monitored locations excluding the IN and IE locations. The Zn concentration of $1.27 \mu\text{gm}^{-3}$ at CB locations was quite substantial in view of the insignificant anthropogenic activities like vehicular traffic, which was considered as one of the main source of airborne Zn. One possibility for such high (but almost equal Zn concentrations at all the locations) might be due to weathering of galvanized iron sheets, which were extensively used as roofing for houses all over Shillong. Zn

Table 5.16 Concentration of zinc in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	1.27	1.41	0.14	3
MP	1.22	1.76	0.33	13
MU	1.18	1.49	0.35	11
HP	1.16	1.66	0.30	13
HU	1.00	1.46	0.42	11
TIF	1.11	1.38	0.21	7
TIB	1.11	1.23	0.12	7
TIG	0.95	1.13	0.16	7
H	1.24	1.30	0.08	2
IN	1.31	1.34	0.04	2
IE	1.32	1.42	0.14	2
A	0.96	1.07	0.05	5

concentrations at North Florida, Leötvös, Khartoum and Riyadh were at least 10 times less than that obtained by us but were comparable with Mumbai and Varanasi for certain categories of locations. The Zn concentrations at Moradabad were exceptionally high (Table 5.17).

Table 5.17 Zinc concentrations in various cities of the world ($\mu\text{g m}^{-3}$)		
Location	Concentration	Reference
North Florida, U.S.A.	0.002	Johansson <i>et al.</i> , 1976
Leötvös, Hungary	0.14	Molnár <i>et al.</i> , 1993
Khartoum, Sudan	0.10	Eltayeb <i>et al.</i> , 1993
City Centre, Riyadh	0.11	Raoof <i>et al.</i> , 1992
Kuwait	0.12	Raveendran <i>et al.</i> , 1992
Vikroli, Mumbai	0.72	Tripathi <i>et al.</i> , 1999
BHU, Varanasi	0.97	Tripathy <i>et al.</i> , 1995
Pheel Khana, Moradabad	13.25	Tripathi <i>et al.</i> , 1990

The mean **Manganese** (Mn) concentrations (Table 5.18) had slightly increased at MP, MU and HP in comparison with CB locations but inexplicably decreased at HU locations. Mn concentrations at traffic intersections were also less in comparison with CB locations, which was because of the generally low concentrations at across locations (Tables A.5.1 to A.5.3). Mn concentration was more at H locations but dropped at IN locations. IE and A locations also showed less Mn concentrations in comparison with CB locations. Mn concentration gradually increased up to a certain height and then decreased again (Table A.5.4). Mn occurs naturally and is ubiquitous in the earth's crust. It had also been detected in trace concentrations in crude petroleum oil (Hofstader *et al.*, 1974). It is also added into gasoline in the form of methyl cyclopentadienyl manganese tricarbonyl (MMT) as an octane enhancer. The use of MMT is on increase in unleaded petrol. The trimodal

Table 5.18 Concentration of manganese in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	0.57	0.81	0.33	3
MP	0.67	1.56	0.44	13
MU	0.60	1.06	0.30	11
HP	0.64	1.77	0.47	13
HU	0.47	1.01	0.30	11
TIF	0.28	0.51	0.13	7
TIB	0.40	0.66	0.20	7
TIG	0.21	1.27	0.47	7
H	0.67	0.71	0.05	2
IN	0.36	0.46	0.13	2
IE	0.48	0.51	0.03	2
A	0.36	0.54	0.18	5

particle size distribution of Mn established the source as automobiles and suspended dust (Lyonos *et al.*, 1993). The high concentration of Mn at CB locations and slight increase at certain traffic activity related locations could be explained by the bimodal nature of its source. The Mn concentrations found in this study were several times higher than other cities of the world (Table 5.19) but were considerably less in comparison with Mumbai. These higher concentrations appeared to be because of geological nature of the crustal rocks in Shillong but this required further studies to strengthen the assumption.

Table 5.19 Manganese concentrations in various cities of the world (μgm^{-3})		
Location	Concentration	Reference
Leötvös, Hungary	0.01	Molnár <i>et al.</i> , 1993
Khartoum, Sudan	0.10	Eltayeb <i>et al.</i> , 1993

The mean **Cobalt** (Co) concentrations (Table 5.20) had increased 5-10 times

at all categories of locations in comparison with CB locations. Gradual drop in Co concentrations was observed at across locations of all traffic intersections as well as with increasing heights at A locations (Tables A.5.1 to A.5.4). Co had also been found in trace concentrations in crude petroleum oil (Hofstader *et al.*, 1974) and, as such, the sudden high increase at the traffic activity related locations could be attributed to vehicular emissions. The resuspension of Co enriched dust due to vehicular motions and other anthropogenic activities appeared to be another major source of airborne Co in Shillong. The Co concentrations found in this study were higher than other cities of the world and as such were hardly comparable (Table 5.21). There is dearth of data regarding the concentrations of airborne Co in Indian conditions.

Table 5.20 Concentration of cobalt in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	0.02	0.02	0.00	3
MP	0.16	0.26	0.05	13
MU	0.18	0.23	0.03	11
HP	0.17	0.33	0.06	13
HU	0.16	0.20	0.03	11
TIF	0.18	0.19	0.02	7
TIB	0.11	0.13	0.01	7
TIG	0.17	0.21	0.03	7
H	0.17	0.18	0.02	2
IN	0.20	0.21	0.01	2
IE	0.19	0.20	0.01	2
A	0.12	0.18	0.04	5

Table 5.21 Cobalt concentrations in various cities of the world ($\mu\text{g m}^{-3}$)		
Location	Concentration	Reference
Leötvös, Hungry	0.007	Molnár <i>et al.</i> , 1993
Glasgow	0.008	McDonald <i>et al.</i> , 1979a
Chicago	0.003	Dams <i>et al.</i> , 1970

The mean **Potassium (K)** concentrations (Table 5.22) had increased at all categories of locations in comparison with CB locations. The increase was comparatively more at MP, MU, HP and HU where it ranged between 3.5 to 7.0 times. The K concentrations dropped at across locations of all traffic intersections (Tables A.5.1 to A.5.3). K concentration dropped by 50% from H to IN locations. The IE locations also showed slight increase in K concentrations in comparison to CB locations. Concentration of K decreased gradually with increasing heights at A locations (Table A.5.4). The abrupt increase at various locations other than CB could be attributed to the resuspension of dust due to traffic and other anthropogenic

Table 5.22 Concentration of potassium in TSP at various locations in Shillong ($\mu\text{g m}^{-3}$)				
Location	Mean	Max	SD	Sample Size (N)
CB	0.73	0.99	0.26	3
MP	3.95	8.67	2.04	13
MU	2.61	6.41	1.72	11
HP	5.28	9.84	3.21	13
HU	3.03	8.66	2.49	11
TIF	1.88	2.94	0.55	7
TIB	1.27	2.21	0.54	7
TIG	1.61	1.95	0.29	7
H	1.64	1.97	0.46	2
IN	0.82	1.03	0.29	2
IE	1.04	1.22	0.27	2
A	1.42	1.94	0.41	5

activities and appeared to be the main source of airborne K in Shillong. The concentration of K found in this study was several times higher than of cities in North Florida and Leötvös but were comparable with those of Khartoum for certain locations of Shillong (Table 5.23).

Table 5.23 Potassium concentrations in various cities of the world (μgm^{-3})		
Location	Concentration	Reference
North Florida, U.S.A.	0.006	Johansson <i>et al.</i> , 1976
Leötvös, Hungry	0.44	Molnár <i>et al.</i> , 1993
Khartoum, Sudan	1.11	Eltayeb <i>et al.</i> , 1993

The mean **Magnesium** (Mg) concentrations (Table 5.24) also increased at all categories of locations in comparison with CB locations. The increase was comparatively more at MP, MU, HP and HU where it ranged between 7.0 to 9.0 times. Mg concentration dropped at across locations of all the traffic intersections (Tables A.5.1 to A.5.3). Concentration of Mg dropped from H to IN locations. IE

Table 5.24 Concentration of magnesium at Various Locations In Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	0.83	0.99	0.18	3
MP	7.81	10.26	1.16	13
MU	6.24	8.48	1.69	11
HP	7.81	17.88	3.46	13
HU	6.06	9.16	2.22	11
TIF	1.94	2.67	0.52	7
TIB	2.68	3.80	0.87	7
TIG	3.08	5.13	1.53	7
H	7.81	17.88	3.46	13
IN	6.06	9.16	2.22	11
IE	1.43	2.02	0.84	2
A	3.88	5.56	1.16	5

locations also showed slight increase in Mg concentrations in comparison to CB locations. Mg concentration increased gradually with increasing heights up to a certain heights and then dropped again at A locations (Table A.5.4). The sudden increase in Mg at various locations other than CB could also be attributed to the resuspension of dust due to traffic and other anthropogenic activities. The concentration of Mg found at CB locations was comparable with $0.99 \mu\text{gm}^{-3}$ for Khartoum observed by Eltayeb *et al.* (1993).

The mean **Sodium** (Na) concentrations (Table 5.25) also increased at all categories of locations in comparison with CB locations. The increase was comparatively more at MP, MU, HP and HU where it ranged between 2.0 to 4.0 times. Na concentration gradually dropped at across locations of all the traffic intersections (Tables A.5.1 to A.5.3). Concentration of Na dropped by 27% from H

Table 5.25 Concentration of sodium in TSP at various locations in Shillong (μgm^{-3})				
Location	Mean	Max	SD	Sample Size (N)
CB	3.19	3.89	0.67	3
MP	7.72	17.71	3.80	13
MU	7.29	13.70	3.42	11
HP	12.79	20.36	5.23	13
HU	14.04	31.83	7.94	11
TIF	7.99	18.81	5.18	7
TIB	5.49	10.73	2.98	7
TIG	10.51	24.60	6.42	7
H	17.56	22.07	6.37	2
IN	12.75	14.30	2.20	2
IE	13.66	26.13	17.63	2
A	12.11	18.81	3.69	5

to IN locations. IE locations also showed 4 times increase in Na concentrations in comparison to CB locations. Concentration of Na gradually dropped with increasing heights at A locations (Table A.5.4). The sudden increase in Na at various locations in comparison with the controls could be attributed to the resuspension of dust due to traffic and other anthropogenic activities. Concentration of Na in Shillong was less in comparison with Glasgow and Chicago but was comparable with San Francisco for CB locations (Table 5.26).

Table 5.26 Sodium concentrations in various cities of world (μgm^{-3})		
Location	Concentration	Reference
Glasgow	0.33	McDonald <i>et al.</i> , 1979a
Chicago	0.46	Dams <i>et al.</i> , 1970
San Francisco	4.45	John, W. <i>et al.</i> , 1973

5.4.2 Enrichment factor analysis for elements

The elemental analyses of suspended particulates is useful in providing information about the extent of pollution levels but information about the sources of these pollutants is hardly available with these data which otherwise could be quite vital for planning and execution of the control measures. To obtain the sources of elements in aerosols, the enrichment factor (EF) of elements had been used to indicate the extent of contribution of sources other than natural crust to the ambient levels (Rojas *et al.*, 1990). The EF for element X in an aerosol sample is defined as:

$$\text{Enrichment Factor (EF}_X\text{)} = [(C_X/C_{Fe})_{\text{Air}} / (C_X/C_{Fe})_{\text{Crust}}] \quad (5.2)$$

(where C_X is concentration of element X, and C_{Fe} is the concentration of iron in both ambient air and crustal materials)

Element Al, Ti and Si were also used as reference element apart from Fe (Macias *et al.*, 1981). In studies of marine aerosol Na and Cl were most frequently used reference elements (Duce *et al.*, 1976). There is no widely accepted rule for choice of reference element. The element Fe had been chosen as a reference in this work due to its wide acceptability as a reference element. However, using Fe as reference element might have hidden the contribution from anthropogenic sources containing this element (Hashimoto, 1992). The average relative global rock-crust composition from Mason, (1966) was used as the reference crustal composition here. The EF had been calculated taking cumulative arithmetic mean concentrations of elements for all the locations of Shillong. The EF close to unity indicated soil dispersion source whereas the EF significantly greater than unity signified an influence of anthropogenic activities. By comparing EFs for various elements at different places in the world it was possible to estimate the sources of pollution other than soil.

The EF results are provided at Table 5.27 together with the EF obtained by other workers for other major cities of the world. On the basis of the EF obtained for Shillong, the elements were categorized broadly into 4 (four) categories of i) non-or insignificantly enriched elements ($EF \leq 2.0$), ii) slightly enriched elements ($EF \leq 5.0$), iii) moderately enriched elements ($EF \leq 100.0$), and iv) highly enriched elements ($EF > 100$).

The elements of Cr, K, Mg and Na fell under the 1st category as these elements had EF near unity and thus were of soil origin with little or no impact of other sources. The similar EF for K had been obtained in West Virginia while the EF

Table 5.27 Enrichment factors for elements at Shillong and other cities.											
Element	Shillong (this work)	Kanpur (Joshi, 1981)	West Virginia (Lewis <i>et al.</i> , 1980)	Khartoum (Eltayeb <i>et al.</i> , 1993)	Glasgow (McDonal d <i>et al.</i> , 1979a)	Brisbane (Chan <i>et al.</i> , 1997)	California (Chan <i>et al.</i> , 1997)	Kashima (Chan <i>et al.</i> , 1997)	Rural, Hungry (Molnár <i>et al.</i> , 1993)	Suburban , Hungry (Molnár <i>et al.</i> , 1993)	City Centre, Hungry (Molnár <i>et al.</i> , 1993)
Pb	498.4	131.7	4200.0	64.0	-	6650.0	5950.0	136.5	824.0	2950.0	7710.0
Ni	2.6	24.2	-	2.1	-	-	-	-	26.1	25.6	40.9
Cu	38.7	35.5	-	1.1	-	-	-	-	68.0	79.9	158.0
Cd	2659.6	-	-	-	-	-	-	-	-	-	-
Cr	1.9	35.6	-	1.3	11.0	0.0	135.0	7.5	59.4	42.1	57.7
Fe	1.0	-	1.0	1.6	1.0	2.7	25.5	1.5	2.9	3.3	5.1
Zn	79.4	37.2	42.0	27.0	822.0	725.0	1750.0	382.5	335.0	324.0	1001.0
Mn	5.0	3.9	-	1.6	4.0	8.4	19.1	0.6	3.1	5.6	5.9
Co	29.0	-	-	-	13.0	-	-	-	39.5	67.5	83.3
K	0.4	5.6	1.0	0.8	-	4.5	3.3	2.1	6.4	5.9	7.2
Mg	1.1	-	-	0.8	-	4.6	2.3	-	-	-	-
Na	1.8	-	-	-	7.0	25.0	7.5	5.5	-	-	-

for Khartoum city was almost same for Cr, K and Mg but higher for Kanpur. Ni and Mn fell under 2nd category. These elements showed slight enrichment. As mentioned in sub-section 5.4.1 above, both Ni and Mn had been traced in crude petroleum oil while Mn was used in petrol in the form MMT as octane enhancer. As such, non-crustal source like vehicular emissions were other likely source for enrichment of these elements. The EF for Ni in Shillong was comparable at Khartoum but was found to be considerably high for rural, suburban and city centre in Hungary. The EF for Mn was less for Khartoum and Kashima, Japan but was comparable with Glasgow, Kanpur and rural Hungary while higher for Brisbane, California, suburban and a city centre in Hungary. We observed that the enrichment of these elements increased with increase in traffic and related activities. Co, Cu and Zn fell under 3rd category of moderately enriched elements. The EF among these elements was highest for Zn. Though, enrichment of Cu and Zn could be characterized by influence of traffic because Zn compounds were extensively used as oxidants (zinc carboxylate complexes and zinc sulfonates) and also as detergents/dispersant improvers for lubricating. Tyre wear had also been reported to contribute significantly to the Zn load in street dust (Stigliani, 1991). Oxidation of lubricating oil was also found to release Zn and Cu. But the high enrichment of Zn in Shillong appeared to be more from the weathering of galvanized sheets because of the reasons explained in sub-section 5.4.1 above. The enrichment of Cu appeared to be due to specific crustal composition in absence of any known source of the same and this exposed the weakness of using one general natural-crust composition as reference in calculating the enrichment factors. Therefore, the continental crust

composition of the corresponding city, if available, should be used in calculating enrichment factors to avoid such ambiguities. The origin of Co was less clear. The burning of fossil fuels including coal had been associated with high Co concentrations. The winter season in Shillong experiences high use of coal combustion for house warming due to its temperate climate and thus enrichment of Co could be attributed to this activity. Comparison of EF for Cu showed that EF for Khartoum was less than for Shillong, comparable for Kanpur and high for rural, suburban and city centre in Hungary. EF for Zn had been less for Khartoum and Kanpur and high for Glasgow, Brisbane, California, Kashima, rural, suburban and city centre in Hungary in comparison with Shillong. EF for Co was less for Glasgow than for Shillong, comparable for rural Hungary and high for suburban and city centre in Hungary. Pb and Cd were the most highly enriched elements in Shillong falling under the 4th category. The high enrichment of Pb was expected due to high traffic activities in Shillong. The EF for Pb in Shillong was more than Khartoum, Kashima and Kanpur but less in comparison with Brisbane, California, rural, suburban and city centre in Hungary. Unexpectedly, Cd was the highest enriched element in Shillong. Apart from its presence in crude petroleum oil, Cd as an impurity of zinc was also found in significant amounts in galvanized sheets and, as such, the enrichment of Cd could be due to high traffic activities and high use of galvanized sheets in Shillong. The EF for Cd could not be compared with other cities of the world due to non-availability of similar data.

Another possibility for enrichment of some elements in Shillong appeared to be the transport of elements from long distances as some workers had observed

enrichment of certain elements (Cu and Zn) by a factor of 10 to 100 at very remote areas far from any industrial and other activities. It will be interesting to study the levels of such elements in the remotest parts of the country to understand their transport behaviour.

The category wise enrichment factors (EF) for all categories of locations (Tables A.5.5 to A.5.10) provided a better understanding of their most likely source at a particular location.

The EF of elements for CB, MP, MU, HP and HU locations (Table A.5.5) indicated that Cu, Cd, Zn and Mn were highly enriched at CB locations in comparison with the anthropogenic activity related locations of MP, MU, HP and HU. Even Pb showed significant enrichment at CB location. There were no known sources of these elements in CB areas due to their pure residential nature. Crustal composition appeared to be the likely possibility for enrichment of Cu while high enrichment of Cd and Zn appeared to be from the weathering of galvanized sheets used extensively in Shillong for housing. Enrichment of Pb at CB locations appeared to be due to transport of Pb from traffic activity related locations accentuated by frequent wind direction changes and high wind speed conditions in Shillong. The high enrichment of Mn at CB locations emphasized its origin as crustal in nature with little contribution from vehicular emissions. The weakness of using one general natural-crust composition as reference in calculating the enrichment factors is more strongly felt by these results. Ni and Cr got slightly enriched at traffic activity related locations showing the influence of non-crustal sources. K, Mg and Na hardly showed any enrichment.

The EF of elements for TIF, TIB and TIG locations (Tables A.5.6 to A.5.8) showed high variations in EF (398-2059) for Pb with no definite patterns at across direction locations of three intersections. In general, The Pb was more enriched at traffic intersections than at across locations at north and south signifying its non-crustal origin. Ni was enriched more at two traffic intersection locations in comparison with its across locations indicating non-crustal factor for its enrichment. Cu was more enriched at across locations in comparison to intersection locations of highways. This was indicative of the enrichment of Cu in Shillong due to crustal composition. Enrichment of Cd was highly varied at across locations with no definite patterns suggestive of location specific enrichment characteristics due to factors explained earlier. Cr appeared to be slightly enriched due to non-crustal factor at TIB locations but not at TIF and TIG. Enrichment of Zn also did not show any definite enrichment patterns signifying location specific enrichments. Mn, Co, K, Mg and Na are either very little or not enriched.

The EF of elements for H and IN locations (Table A.5.9) indicated that Ni, Mn and Na were more enriched on highways and Pb, Cd, Zn and Co were more enriched at IN locations while Cu was equally enriched at H and IN. Cr, K and Mg were not enriched at these locations.

The EF of elements for IE locations (Table A.5.9) showed that K and Mg were not enriched while Ni, Cr, Mn and Na were slightly enriched. Zn and Co were moderately enriched and Cd and Pb had been highly enriched elements.

The EF of elements for A locations (Table A.5.10) showed that enrichment of Pb, Ni, Co and Na gradually decreased by increasing heights signifying

enrichment of these elements with traffic related factors that include vehicular emissions as well as resuspended dust of particles belonging to particular size groups. The enrichment of Cu, Cd, Zn and Mn increased with increasing heights signifying their specific nature of enrichment. Cr, K and Mg were not enriched at these locations.

5.4.3 Correlation analysis of elements

Correlation analysis provides information about the association between the elements in a data set. The use of correlation coefficients allows a quantitative estimate of temporal variations of two elements. Highly correlated elements may come from same prime source or may have been transported together. The Pearson Correlation Coefficients between the elements at CB, MP, MU, HP and HU locations only were obtained and discussed. The correlations between elements and total traffic density were also obtained to find their relationships because the vehicles and associated activities were considered as the key sources of pollutant loadings at the breathing level ambient air of Shillong.

The correlations between elements at CB locations (Table A.5.11) revealed that Pb had moderately positive correlations with Cd and K but negative correlations with remaining elements implying that Pb and part of Cd had similar source and the Pb, Cd and K were carried together to the CB locations from their point of origin. Ni had strong positive correlations with Cu, Cr, Zn, Co, Mg and Na and moderately positive correlations with Fe that was suggestive of their source as soil. Likewise, Cu had strong positive correlations with Cr, Zn, Co, Mg and Na, Cr had strong

positive correlations with Fe, Zn, Co, Mg and Na, Fe had strong correlations with Zn, Mn, Co, Mg and Na and Zn had strong correlations with Co, Mg and Na signifying that these elements also had the common origin preferably soil. Mn had strong positive correlation with K, Co had strong positive correlations with Mg and Na and Mg had strong correlations with Na implying soil as the source for these elements.

The correlations between elements at MP locations (Table A.5.12) revealed that Pb had moderately positive correlations with Cu, Cr, Co and significantly positive correlation with Zn. This indicated that vehicular emissions were associated in build up of these elements in the atmosphere whereas the moderately positive correlations of Pb with soil derived elements like K, Mg and Na appeared to be because of resuspension of dust due to vehicular activities. Ni had moderate positive correlations with Mn, Co, K and Na and weak positive correlations with Mg signifying that a part of Ni has soil origins. Cu had strong and significant positive correlations with Zn and Mg and moderate with Cd, Cr, Co and Na signifying that Zn had two likely sources. K had strong and significant positive correlations with Mg. Other elements had mostly weak correlations.

The correlations between elements at MU locations (Table A.5.13) in general became weak. Ni had moderate positive correlations with Cd and Cu had moderate positive correlations with Cr, Zn and Mn signifying their part origin as vehicular emissions. Cr had moderate positive correlations with Mn, K and Mg and Fe had moderate positive correlations with Zn and Mg indicating the source as soil. The moderate positive correlation of Zn with Co was perhaps by weathering of

galvanized sheets as hypothesized earlier.

The correlations between elements at HP locations (Table A.5.14) illustrated that Pb had significant positive correlations with Mn, Co, K and Mg that indicated that the resuspension of dust increased with increased traffic density whereas the moderate positive correlation of Pb with Cd and Zn implied that part of these elements had a common source of origin i.e. vehicular emissions. Ni had moderate positive correlations with Mn, K, Mg and Na signifying their source as soil. Cu had significantly positive correlations with Cr. Zn had moderate positive correlations with Co and Mg. Mn had significantly positive correlations with Co, K and Mg, Co had significantly positive correlations with Mg and Mg had significantly positive correlations with K implying their source as soil.

The correlations between elements at HU locations (Table A.5.15) exemplify that Pb had moderate positive correlations with Cd, Zn and Co suggestive of their partly common source as vehicular emissions. Ni had moderate positive correlations with Fe, Zn, and Na and significantly positive with K indicating the source as soil. Cu had moderate positive correlation with Cd, Cr, Zn and Mn again implying the source partly as vehicular emissions. The moderate positive correlations of Cr with Na, Fe with Mn, K, Mg, Zn with Na, Mn with K, Mg, Na, K with Mg and Mg with Na were suggestive of their common source as soil.

From the correlations of elements at the CB, MP, MU, HP and HU locations, we observed that at plain locations of MP and HP the soil originated elements like K, Mg and Na also showed positive correlations with Pb suggesting that the resuspended soil had become enriched with Pb. Almost similar associations between

elements were observed by Foner *et al.* (1992) at Tel Aviv and Arad in Israel.

The correlations of ρ_T with elements at MP, MU, HP and HU locations (Table A.5.16) indicated that in general, the correlations of ρ_T with elements became relatively better from MP to HU locations with Pb, Ni, Cd, Zn and Co implying that a part of these elements in ambient air of Shillong could be associated with vehicular emissions. The soil-derived elements like K, Mg and Na showed very weak correlations.

5.4.4 Source apportionment of elements using factor analysis technique

Factor Analysis is a multivariate statistical analysis technique considered as a highly useful tool to describe and interpret the elemental results in a better way. Since, the airborne elemental concentrations are subjected to a large number of variations, factor analysis can be applied to deduce the interrelationships between elemental concentrations and the sources responsible for their origin. We have performed factor analysis on elemental data for MP, MU, HP and HU locations using Principal Component Analysis method with Varimax Rotation as explained in Chapter 4.5.4. The following 5-factors were considered:

Factor 1-Vehicular emissions

Factor 2-Resuspended dust due to vehicular motions

Factor 3-Mixed source of vehicular emissions and resuspended dust

Factor 4-Weathering of building materials and

Factor 5-Refuse/domestic fuels burning

Factor loadings, Eigen values and % total variance explained the strength of the sources virtually represented by these factors. This got established further by communality of the common factors that indicated the total variance of the variables accounted by the above-mentioned 5-factors.

At MP locations (Table 5.28), 4 factors were obtained with Eigen values above unity that accounted for 87% of the total variance for elements. The 1st factor was characterized by very high and significant loadings for Mg, Zn and Cu and, as such, could be related to resuspended dust and the moderate loadings for Co and Pb could be related with vehicular emissions thus indicating this factor of mixed characteristics. The 2nd factor had high and significant loadings for Ni and Mg and moderate loadings for Co and K signifying the factor to be purely resuspended dust

Table 5.28 Factor loadings for elements at MP locations						
Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Pb	0.41	0.01	0.10	-0.26	0.71*	0.75
Ni	0.01	0.77*	0.23	0.27	-0.16	0.75
Cu	0.79*	0.10	-0.52	-0.10	0.17	0.94
Cd	-0.07	-0.03	-0.89*	0.13	-0.05	0.83
Cr	0.26	0.05	-0.43	-0.09	0.70*	0.76
Fe	0.22	-0.81*	0.40	0.11	-0.23	0.94
Zn	0.84*	-0.02	0.23	-0.16	0.33	0.89
Mn	0.00	0.16	-0.09	0.91*	-0.09	0.88
Co	0.54	0.65	0.06	-0.38	0.18	0.91
K	0.12	0.48	0.34	0.30	0.72*	0.96
Mg	0.88*	0.09	0.06	0.29	0.16	0.90
Na	0.35	0.74*	-0.03	0.39	0.26	0.90
Eigen Values	4.25	2.29	1.68	1.32	0.86	
%Total Variance	35.43	19.07	14.00	10.98	7.14	
% Cumulative Variance	34.43	54.50	68.50	79.48	86.62	

due to vehicular motions. The 3rd factor had only moderate loadings for Fe and K. The 4th factor had high and significant loadings for Mn indicating a unique fugitive source that might be the refuse burning. The 5th factor had Eigen value less than unity and thus was not considered to be an important factor. It had high loadings for K, Pb and Cr and possibly it was the domestic fuel burning.

At MU locations (Table 5.29), all 5 factors were found with Eigen values above unity that accounted for 84% of the total variance in the elements. The 1st factor was characterized by very high and significant loadings for K and high loadings for Mg with moderate loadings for Cr and Pb thus indicating this factor of mixed characteristics. The 2nd factor had high and significant loadings for Zn and moderate loadings for Co and probably implied the weathering of building materials

Table 5.29 Factor loadings for elements at MU locations						
Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Pb	0.24	-0.91*	0.03	-0.12	-0.11	0.92
Ni	-0.68	0.07	-0.15	0.22	-0.35	0.68
Cu	0.14	0.14	0.23	0.02	0.91*	0.93
Cd	-0.39	-0.23	-0.03	0.73*	-0.25	0.82
Cr	0.38	0.01	0.42	0.72*	0.13	0.87
Fe	-0.00	0.22	-0.87*	-0.13	0.00	0.83
Zn	0.04	0.91*	-0.03	-0.17	0.13	0.89
Mn	0.01	0.27	0.85*	-0.17	0.27	0.91
Co	0.16	0.66	0.12	-0.30	-0.45	0.78
K	0.90*	-0.11	0.16	0.13	0.01	0.87
Mg	0.92	0.07	-0.31	0.01	-0.06	0.95
Na	-0.08	0.04	0.38	-0.59	-0.40	0.67
Eigen Values	2.83	2.60	2.03	1.54	1.10	
%Total Variance	23.61	21.70	16.91	12.83	9.20	
% Cumulative Variance	23.61	45.31	62.22	75.05	84.25	

as a source. The 3rd factor had high and significant loadings for Mn and moderate loadings for Cr indicating refuse burning as the source. The 4th factor had high and significant loadings for Cd and Cr signifying the source as domestic fuel burning. The 5th factor had significant high loadings for Cu that appeared to be distinctive in nature indicating some unique unidentifiable source.

At HP locations (Table 5.30), 4 factors were obtained with Eigen values above unity that accounted for 81% of the total variance in the elements. The 1st factor was characterized by very high and significant loadings for Pb, Mn, Co and K and moderate loadings for Cr. The unique feature of the factor was that it had no negative loadings. The impact of vehicular emissions was clearly evident because of

Table 5.30 Factor loadings for elements at HP locations						
Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Pb	0.91*	0.07	0.19	0.02	-0.31	0.97
Ni	0.16	-0.50	-0.35	0.68	0.18	0.90
Cu	0.02	0.96*	-0.04	0.10	-0.11	0.96
Cd	0.08	-0.05	0.01	-0.18	-0.95*	0.95
Cr	0.24	0.82*	-0.02	-0.00	0.32	0.84
Fe	0.01	0.30	-0.85*	-0.16	0.19	0.88
Zn	0.08	0.24	0.90*	-0.18	0.18	0.94
Mn	0.83*	-0.03	-0.15	0.09	0.17	0.76
Co	0.83*	0.22	0.12	-0.11	0.21	0.81
K	0.78*	-0.09	0.29	0.12	-0.33	0.83
Mg	0.83*	0.18	0.23	0.37	-0.06	0.92
Na	0.11	0.20	0.07	0.89*	0.11	0.88
Eigen Values	3.90	2.32	1.90	1.54	0.99	
%Total Variance	32.52	19.37	15.87	12.88	8.29	
% Cumulative Variance	32.52	51.89	67.76	80.64	88.93	

significantly high Pb loadings. The 1st factor had also of mixed origin due its high loadings for soil related elements. The 2nd factor was highly loaded for Cu and Cr and could be related with the vehicular emissions. The 3rd factor had high and significant loadings for Zn and, as such, could be related with the weathering of building materials like galvanized sheets. The 4th factor had high and significant loadings for Na and moderate loadings for Ni and could be related with the resuspension of the street dust. The 5th factor had no significant loadings for any elements and thus could be associated with fugitive sources.

At HU locations (Table 5.31), 4 factors were obtained with Eigen values above unity that accounted for 77% of the total variance in the elements. The 1st factor was characterized by very high and significant loadings for Ni and K

Table 5.31 Factor loadings for elements at HU locations						
Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
Pb	-0.08	0.14	0.02	0.01	0.97*	0.95
Ni	0.86*	-0.16	-0.03	-0.11	-0.04	0.80
Cu	0.19	-0.16	0.89*	0.20	0.02	0.91
Cd	-0.36	0.25	0.65	0.08	0.44	0.83
Cr	-0.09	-0.92*	0.17	0.09	-0.11	0.92
Fe	0.27	-0.38	-0.73	0.43	0.01	0.94
Zn	0.52	0.13	0.55	-0.10	0.37	0.74
Mn	0.03	-0.03	0.00	0.98*	0.01	0.94
Co	-0.22	0.86*	0.15	-0.01	0.10	0.83
K	0.71*	-0.09	-0.31	0.37	-0.17	0.78
Mg	0.25	0.45	-0.66	0.28	0.20	0.83
Na	0.60	0.43	0.14	0.31	0.13	0.68
Eigen Values	3.31	2.50	2.15	1.26	0.93	
%Total Variance	27.55	20.87	17.92	10.50	7.74	
% Cumulative Variance	27.55	48.42	66.34	76.84	84.58	

implying the source as resuspended dust. The 2nd factor had high and significant Loadings for Co and moderate loadings for Mg and Na signifying again the source as resuspended dust. The 3rd factor had high and significant loadings for Cu. The similar loadings for Cu were obtained at MU locations as well. The source of Cu at uphill locations appeared to be quite unique in nature and probably had vehicles as the source. It appeared that at high load conditions, the oxidation of lubricating oils increased causing more emission of Cu due to various reactions involved. The 4th factor had loadings for Mn signifying the refuse burning as the source. The 5th factor had high and significant loadings of Pb and moderate loadings for Cd indicating its source as vehicular emissions.

5.5 CONCLUSIONS

On the basis of the results obtained for elemental concentrations at various locations, enrichment factors analysis, correlations and source apportionment of elements using factor analysis, the following conclusions have been drawn:

Elemental Concentrations

- The concentrations of Pb had shown significant increase at traffic activity related locations and were found to be more at steep gradient locations of MU and HU than plain locations of MP and HP.
- The gradual drop in Pb concentrations at across locations of traffic intersections and decrease in concentrations with increasing heights indicated vehicular emissions as the prime Pb source.

- High concentrations of Pb at IN locations were of great concern due to the situation of high number of residential buildings at highways in Shillong.
- The highly 'critical' Pb concentrations at MP, MU, HP and HU locations were also of serious concern.
- The high concentrations of Ni, Cu, Cd, Cr, Zn, Mn and Co invariably pose high health risks. High concentrations of a few elements should have been due to natural rock composition or the weathering of galvanized sheets and, as such attributed to natural occurrence

Enrichment factors for elements

- Cd and Pb were found to be the most enriched elements in Shillong followed by Cu, Zn and Co.
- Ni and Mn were found as slightly enriched elements while Cr, K, Mg and Na had not been enriched.
- The use of one general natural-crust composition as reference in calculating the enrichment factors showed weakness of the model. The continental crust composition of the corresponding city should be used in calculating enrichment factors to avoid such indistinctness.

Correlations analysis for elements

- The association of Pb with Cd and K at CB locations indicated their common transport mechanism.
- The strong correlations of Ni with Cu, Cr, Zn, Co, Mg and Na suggested that part of these elements in ambient air was due to the rock crust composition.

- The association of elements at traffic related locations changed completely with vehicular emission related elements and soil and resuspended dust associated elements showing strong correlations.

Factor analysis for source apportionment of elements

- The 5-factor model for source apportionment of elements was found to be quite suitable as it accounted for almost 84-89% for airborne elemental build up in Shillong.
- The vehicular emissions, resuspended dust and weathering of building materials were amongst the most important factors for presence of elements in TSP at breathing level in Shillong.

CHAPTER 6

CHAPTER 6

SUMMARY OF THE PRESENT WORK AND FUTURE SCOPE

The deleterious effects of air pollution on human health and ecology have aroused global concern. The problem is more intense in urban atmosphere where control measures could hardly keep pace with ever increasing diverse pollution sources. The quandary of air pollution is more acute in developing countries due to want of requisite infrastructure and resources for its monitoring and control. The scanty data on TSP and soot loadings particularly at breathing zone of the people, size distributions of airborne particulates, their transport and behaviour in the atmosphere and elemental compositions have been the guiding force for us to study these aspects in Indian conditions. Under the circumstances, that no National Standards have so far been evolved for soot, it is felt essential to understand their levels because of the serious health hazards posed by this particular pollutant. Uncertainty over the issue of evolvement of number or mass based criteria for fine particulates ($PM_{2.5}$) has been another important aspect, at least for our country, which is in process to set National Standards for this pollutant that directed us to take on the study.

The outcome of the work opens up new areas of studies for assessment of air quality at breathing levels in other cities as well and provides vital information for setting up of National Standards for soot and $PM_{2.5}$.

6.1 SUMMARY OF THE PRESENT WORK

The salient features of the outcome of present work providing an overt scenario of the breathing level air quality of Shillong are summarized point-wise herein:

- ◆ Aerosol sample color had provided a reasonable qualitative estimation of airborne soot as it changed from gray to brown and ultimately to black color at low, medium and high anthropogenic activity areas. The sample colors in the areas located on highways and major roads had mostly been found black.
- ◆ TSP concentrations along highways within the city limits, major roads, residential, residential-cum-commercial, commercial and secretarial areas had been “high” to “critical” levels but showed sharp gradual decrease at across locations in north and south directions and with increase in heights.
- ◆ Diesel vehicles were linked with the increased mass loadings at steep road gradients (uphill).
- ◆ Soot concentrations followed lognormal distribution with TSP and had strong relationships at traffic activity areas. Soot concentrations were high at steep gradient roads than at plain terrains and showed

gradual decrease at across locations in north and south directions.

Significant soot concentration at indoors was a point of concern.

- ◆ Concentration of fine solid particles of $PM_{0.44}$, $PM_{0.88}$ and $PM_{1.77}$ increased at traffic activity related locations. Invariably, concentration of cumulative $PM_{2.5}$ significantly increased at traffic activity related locations. $PM_{1.77}$ concentrations were more at plain locations than uphill locations indicating the probable source as resuspended dust.
- ◆ PM_5 and PM_{10} decreased at traffic activity related locations in comparison with the control locations while $PM_{>10}$ showed less variation. This decrease might be attributed to the dilution effect due to sudden increase in fine particulates.
- ◆ Temporal variations in solid particle concentrations indicated site-specific nature of locations mostly dependent on factors like topographical situation, traffic density and prevailing meteorological conditions.
- ◆ Higher build up of $PM_{0.44}$ and $PM_{0.88}$ could be directly linked to vehicular emissions at traffic activity related locations but build up of $PM_{1.77}$ and $PM_{2.6}$ appeared to be due to coagulation of fine particulates accentuated by high humid conditions of Shillong.
- ◆ The vertical movement of $PM_{0.44}$ and $PM_{0.88}$ up to a certain height had been established. This became significant health risk because of the high number of residential buildings along the highways within

the city limits.

- ◆ Concentration of PM_5 , PM_{10} and $PM_{>10}$ appeared to be influenced more by the natural factors than anthropogenic ones due to their higher concentrations at control locations.
- ◆ Statistical analysis further established that higher build up of $PM_{0.44}$ and $PM_{0.88}$ at MP, MU, HP and HU locations was mainly due to vehicular exhaust emissions.
- ◆ Heavy vehicles were found to be the highest contributor of fine particulate build up at MP, MU, HP and HU locations followed by light vehicles and two wheelers.
- ◆ Vehicular emissions and resuspended dust had been the influencing factors for the solid particles build up at plain locations of MP and HP accounting for 83% and 73% respectively.
- ◆ Vehicular emissions, resuspended dust and gas-particle conversion and coagulation had been the influencing factors for the solid particles build up at uphill locations accounting for 89% and 84% at MU and HU locations respectively.
- ◆ The 5-factor model for source apportionment of solid particles was found to be highly suitable as it accounted for almost 100% for solid particles build up in Shillong.
- ◆ Relationship between solid particle concentrations and meteorological variables was generally weak that again established the site-specific nature of solid particles build up.

- ◆ Relationships of temperature and solid particle concentrations were highly varying for fine particles but the positive relationships with $PM_{>10}$ suggested that perhaps temperature assisted in keeping these particles airborne for considerable time.
- ◆ Humidity also had varying relationships with solid particle concentrations with inverse relationships with $PM_{0.44}$ that obviously demonstrated that high humidity reduced the concentration of this facilitating coagulation.
- ◆ Comparison of solid particle size distributions with image analysis system and optical microscope established that latter could be used with similar precision and accuracy.
- ◆ Scanning electron microscopy was useful in obtaining information about morphology and textural structure of individual airborne particulate including its composition according to shape and texture. This helped in identifying the particulates source.
- ◆ Prevalence of crustal and biogenic particles at control locations, crustal particles with embedded small particles, porous and fluffy soot particles, conglomerates with concentric circular structure of discontinuous fringes and inter planer spacing at traffic activity related locations could be explicitly observed with scanning electron microscopy.
- ◆ High oil-drop concentrations at the locations surrounded by pine trees clearly indicated them as a prime source of its loadings.

- ◆ Lower TSP and soot contents at high oil-drop concentration areas indicated probability of a possible positive role played by these in removal of airborne particulate materials perhaps by coagulation.
- ◆ High ambient temperature and wind speeds increased oil-drop concentrations as evinced from their positive correlations.
- ◆ The $OD_{0.88}$ and $OD_{1.77}$ were the most prevailing and dominant size of oil-drops among all the size groups implying that fine oil-drops fast attained bigger sizes by coagulation and remained airborne for comparatively longer period of time.
- ◆ In general, concentration of $OD_{0.88}$ and $OD_{1.77}$ was higher at control locations establishing further the source as biogenic in origin.
- ◆ Almost 100% oil-drops belonged to the size group of cumulative $OD_{2.5}$ and thus were liable to be inhaled and lodged deep into the respiratory system.
- ◆ Temporal variations in oil-drop concentrations of various size groups indicated sampling locations more site specific and depending on topographical situation, vegetation cover, up to certain extent the traffic density and prevailing meteorological conditions.
- ◆ Higher build up of $OD_{0.44}$ could be linked to the vehicular emissions but the build up of $OD_{0.88}$ and $OD_{1.77}$ appeared to be due to coagulation of fine oil-drops emanated from pine trees/vegetation.
- ◆ Fine oil-drops released at ground level got coagulated to bigger size and moved vertically with further simultaneous coagulation leading to

formation of OD_{1.77}. Any further increase in size appeared to lead for scavenging of oil-drops in the atmosphere.

- ◆ Statistical analysis linked build up of OD_{0.44} to vehicular exhaust emissions. Interestingly this build up was more due to heavy vehicles than two wheelers.
- ◆ Heavy vehicles were found to be the highest contributors of OD_{0.88} build up at MU and HU locations indicating the bias of these vehicles to emit oil-drops of this size group at steep road gradients.
- ◆ Pb concentrations showed significant increase at traffic activity related locations and was found to be more at uphill locations than plain locations.
- ◆ Gradual drop in Pb concentrations at across locations at traffic intersections and decrease in concentrations with increasing heights indicated vehicular emissions as the prime source of Pb in Shillong.
- ◆ High concentrations of Pb at indoors were of great concern due to high number of residential buildings on highways and major roads.
- ◆ Highly 'critical' Pb concentrations at MP, MU, HP and HU locations were also of serious concern.
- ◆ High concentrations of Ni, Cu, Cd, Cr, Zn, Mn and Co invariably indicated high health risks but high concentration of few of these elements was due to natural rock compositions or weathering of galvanized sheets and, as such, appeared uncontrollable.
- ◆ Cd and Pb were found to be the most enriched elements in Shillong

followed by Cu, Zn and Co.

- ◆ Ni and Mn were found to be slightly enriched elements while Cr, K, Mg and Na were not enriched.
- ◆ Use of one general natural-crust composition as reference in obtaining enrichment factors showed weakness of the model. The continental crust composition of the corresponding city in calculating enrichment factors shall avoid such indistinctness.
- ◆ Association of Pb with Cd and K at control locations indicated their common transport mechanism while strong interrelationship of Ni with Cu, Cr, Zn, Co, Mg and Na suggested that part of these elements in ambient air were due to the rock crust composition
- ◆ The 5-factor model for source apportionment of elements was quite suitable as it accounted for almost 84-89% for airborne elements build up in Shillong.
- ◆ Vehicular emissions, resuspended dust and weathering of building materials were most important factors for airborne elements.

6.2 FUTURE SCOPE OF WORKS

The present work has provided vital information about air quality of Shillong at breathing level in terms of TSP, soot, solid particles and oil-drop size distributions and elemental compositions. It is expected that the outcome of the present work will assist in evolvement of national standards for soot. It will also provide valuable insight for an appropriate decision on whether to adopt mass based or number based

standards for PM_{2.5}. The following investigations may provide a new understanding for the atmospheric pollution problems and may facilitate in adoption of control strategies for protecting people from serious health risks:

- ◆ Present study offers an exhaustive model to characterize breathing level ambient air quality in urban habitat. Hence, such studies may be extended to other cities in the north-eastern region and the country as a whole.
- ◆ The particle size distribution studies should be carried out for both particle mass and particle number concentrations to understand the merits and demerits of these techniques for evolvement of appropriate National Standards.
- ◆ The high TSP and soot loadings at Shillong, the “Scotland of East”, breaks the myth of its being a air pollution free city. Such high concentration of these pollutants at breathing level makes it imperative to study the levels of soluble inorganic and organic concomitants in the atmosphere to understand the atmospheric pollution levels of the city in its totality.
- ◆ High amount of fine oil-drops released from vegetation sources necessitates studying the aspect of their health impacts and their role, if any, in natural scavenging of airborne particulates. Characterization of oil-drops at control and breathing level samples with gas-liquid chromatograph shall help in identification of their chemical composition and thus the extent of health risks.
- ◆ Studying elemental composition of the earth crust for various cities in the country for better understanding of the enrichment of elements in the urban

atmosphere.

- ◆ The present study has been performed at the time when unleaded petrol and Euro-I and Euro-II compliant vehicles have not been introduced in Shillong. Future works on these aspects can be helpful in understanding the impact of introduction of the same in Shillong.
- ◆ The use of methyl cyclopentadienyl manganese tricarbonyl (MMT) is on increase in unleaded petrol leading to increase in concentration of this toxic element in the ambient air. The future research efforts should be directed to assess its trends in atmosphere, which will be useful in assessment of its health implications.
- ◆ Significant proportion of the people resides along the highways and major roads of Shillong. They are invariably exposed to elevated concentrations of TSP, soot, fine particulates ($PM_{2.5}$), Pb and other trace elements of toxic nature. The simultaneous health surveys would reveal the nature of medical problems and associated morbidity and mortality rates. The information will be useful in assessment of the actual quantum of the pollution problems and will assist in taking appropriate control measures.

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List of Research Papers Based on This Study

1. **"Assessment of Total Suspended Particulates and Particle Size of Breathing Level Ambient Air of Shillong"** S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, Presented in the Symposium on **"Pre concentration and Characterisation of Trace Constituents 'PACT'-An Essentiality"**, 26-27th May, 1999, Shillong, India.
2. **"Mass Loadings and Size Distributions of Vehicular Particulates at Breathing Level in Ambient Air of Shillong (India)"**, K. K. Dwivedi, S. C. Katiyar, D. T. Khathing, Accepted for Presentation in 8th International Conference on **"Urban Transport and Environment in the 21st Century"**, 13-15 March 2002, Seville, Spain.
3. **"Assessment of Breathing Level Ambient Air Quality of Shillong, India: Part-I Total Suspended Particulates"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, *Indian Journal of Environment Protection*, 000 (2002), 000.
4. **"Assessment of Breathing Level Ambient Air Quality of Shillong, India: Part-II Particle Size Distributions"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, *Indian Journal of Environment Protection*, 000 (2002), 000.
5. **"Characterization of Exhaust Emissions from Gasoline and Diesel Powered Vehicles"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, *Pollution Research*, 000 (2002), 000.
6. **"Zonation of Greater Shillong in Terms of Breathing Level Air Quality "**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, under preparation.
7. **"Breathing Level Air Quality Along and Across the Highways in Shillong (India)"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, under preparation.
8. **"Quantitative Estimation of Toxic Elements in Suspended Particulate Matters in Shillong, India By Atomic Absorption Spectrophotometer"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, under preparation.
9. **"Characterization of Suspended Particulate Matters in Shillong, India By Cluster Analysis"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, under preparation.
10. **"Influence of Elevation on Mass Loadings of Suspended Particulate Matter in Shillong, India"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, under preparation.

APPENDIX

I

Table A.1.1 Summary statistics of vehicular density at MP locations

Location Code	TW			LV			HV			Pr			Sample Size (N)
	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	
MP1	76.7	43.8	117	602.7	373.4	1029	636.3	215.1	884	1315.7	626.4	2030	3
MP2	123.3	47.4	174	791.3	495.4	1358	698.0	177.8	881	1612.7	712.8	2413	3
MP3	203.5	44.6	235	1063.5	202.9	1207	814.0	100.4	885	2081.0	258.8	2264	2
MP4	156.0	77.8	211	1153.0	196.6	1292	807.5	122.3	894	2156.5	297.7	2367	2
MP5	116.0	48.1	150	1206.5	170.4	1327	874.0	58.0	915	2196.5	64.4	2242	2
MP6	399.5	47.4	433	1722.0	294.2	1930	975.5	103.9	1049	3097.0	445.5	3412	2
MP7	389.3	109.9	510	1979.0	950.2	2849	895.7	10.7	905	3264.0	1050.0	4257	3
MP8	151.3	127.0	298	1597.7	1153.7	2927	319.7	187.5	536	2068.7	1468.1	3761	3
MP9	125.7	32.2	161	1465.7	671.6	2145	313.3	119.3	403	1904.7	676.1	2646	3
MP10	99.0	38.2	126	1254.5	135.1	1350	197.5	34.7	222	1551.0	131.5	1644	2
MP11	70.0	58.0	111	178.0	161.2	292	168.0	111.7	247	416.0	330.9	650	2
MP12	217.5	16.3	229	2178.0	60.8	2221	10.0	5.7	14	2405.5	82.7	2464	2
MP13	308.0	171.1	429	1442.0	28.3	1462	954.0	39.6	982	2704.0	103.2	2777	2

Table A.1.2 Summary statistics of vehicular density at MU locations

Location Code	TW			LV			HV			Pr			Sample Size (N)
	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	
MU1	200.0	124.5	288	1170.5	497.1	1522	934.5	78.5	990	2305.0	700.0	2800	2
MU2	285.0	108.9	362	1577.0	711.4	2080	934.5	212.8	1085	2796.5	1033.1	3527	2
MU3	376.0	40.4	423	2067.3	396.1	2304	341.3	147.4	482	2785.0	550.3	3139	3
MU4	663.5	37.5	690	2867.5	282.1	3067	241.5	31.8	264	3772.5	351.4	4021	2
MU5	156.0	141.4	255	184.0	205.1	329	62.5	36.1	88	401.5	382.5	672	2
MU6	445.7	84.3	541	2509.0	570.9	3168	760.3	91.6	849	3715.0	481.5	4249	3
MU7	385.7	84.9	479	1936.7	438.3	2269	827.7	135.7	952	3150.0	647.8	3700	3
MU8	188.5	12.0	197	791.5	234.1	957	856.5	21.9	872	1836.5	200.1	1978	2
MU9	154.5	23.3	171	816.5	9.2	823	828.5	132.2	922	1799.5	164.8	1916	2
MU10	98.0	28.7	131	647.7	172.5	830	600.7	82.3	668	1346.3	241.8	1539	3
MU11	84.3	14.8	97	628.3	108.6	730	677.3	81.4	771	1390.0	186.2	1598	3

Table A.1.3 Summary statistics of vehicular density at HP locations

Location Code	TW			LV			HV			Pr			Sample Size (N)
	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	
HP1	659.0	131.5	752	3586.0	7.1	3591	1165.0	107.5	1241	5410.0	17.0	5422	2
HP2	755.0	281.4	954	3340.5	210.0	3489	1084.5	54.5	1123	5180.0	17.0	5192	2
HP3	761.3	249.0	1001	3437.7	1434.5	4372	766.3	99.6	879	4965.3	1713.7	6252	3
HP4	701.7	236.3	877	3439.7	1469.8	4793	270.7	96.8	380	4412.0	1698.6	5866	3
HP5	971.0	465.3	1300	3857.5	2315.8	5495	272.5	10.6	280	5101.0	2791.7	7075	2
HP6	810.3	170.2	1005	5441.3	1395.4	6988	361.0	32.5	398	6612.7	1344.4	8026	3
HP7	1449.3	647.9	1918	6399.3	765.0	7083	1294.0	177.2	1497	9142.7	1520.8	10498	3
HP8	540.3	252.3	780	3913.7	1271.2	4670	490.7	188.4	695	4944.7	1662.6	6145	3
HP9	1608.0	419.7	1980	7423.0	1498.2	9080	1363.7	472.6	1640	10394.7	1611.2	11866	3
HP10	830.5	538.1	1211	3646.0	2436.7	5369	673.5	507.0	1032	5155.0	3474.7	7612	2
HP11	1070.7	231.7	1327	4653.3	312.4	4998	507.3	190.3	727	6231.3	415.8	6627	3
HP12	766.3	58.8	830	4082.3	1096.4	5079	578.3	174.4	778	5427.0	1282.6	6687	3
HP13	997.3	268.7	1260	2818.7	634.7	3545	522.3	48.3	556	4338.3	838.4	5272	3

Table A.1.4 Summary statistics of vehicular density at HU locations

Location Code	TW			LV			HV			Pr			Sample Size (N)
	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	
HU1	628.0	91.9	693	3417.5	248.2	3593	1224.0	67.9	1272	5269.5	88.4	5332	2
HU2	972.0	257.4	1154	4714.5	1314.5	5644	1304.0	260.2	1488	6990.5	1832.1	8286	2
HU3	749.0	220.6	905	3702.5	68.6	3751	1222.5	58.7	1264	5674.0	347.9	5920	2
HU4	508.0	130.1	600	2368.0	49.5	2403	1155.0	58.0	1196	4031.0	22.6	4047	2
HU5	589.3	92.1	645	2735.7	356.7	3147	1137.7	146.3	1292	4462.7	533.8	5079	3
HU6	1125.0	158.8	1241	3292.3	447.5	3699	846.0	86.7	929	5263.3	667.9	5793	3
HU7	1361.0	244.4	1640	5370.7	2336.2	7578	514.7	77.2	576	7246.3	2375.1	9376	3
HU8	1133.5	214.3	1285	5825.5	1108.0	6609	1171.0	247.5	1346	8130.0	1569.8	9240	2
HU9	1227.7	161.2	1350	5125.0	303.5	5428	1254.3	141.0	1372	7607.0	579.3	8088	3
HU10	1238.5	82.7	1297	4303.0	1226.1	5170	1323.0	80.6	1380	6864.5	1224.0	7730	2
HU11	808.5	67.2	856	4202.0	968.7	4887	1259.5	309.0	1478	6270.0	726.9	6784	2

Table A.1.5 Summary statistics of vehicular density at TIF locations													
Location Code	TW			LV			HV			p _T			Sample Size (N)
	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	
TIFN3	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIFN2	2.5	102.5	145	145.5	205.8	291	3.0	4.2	6	221.0	312.5	442	2
TIFN1	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIF0	1419.5	186.0	1551	4941.5	688.0	5428	1351.0	29.7	1372	7712.0	531.7	8088	2
TIFS1	98.0	46.7	131	239.0	8.5	245	7.5	9.2	14	344.5	47.4	378	2
TIFS2	63.0	89.1	126	106.0	149.9	212	4.0	5.7	8	173.0	244.7	346	2
TIFS3	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2

Table A.1.6 Summary statistics of vehicular density at TIB locations													
Location Code	TW			LV			HV			ρ_T			Sample Size (N)
	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	
TIBN3	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIBN2	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIBN1	120.1	169.7	240	365.0	516.2	730	1.0	1.4	2	486.0	687.3	972	2
TIB0	802.5	789.4	1361	5312.5	3235.0	7600	844.5	666.8	1316	6959.5	4691.7	10277	2
TIBS1	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIBS2	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIBS3	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2

Table A.1.7 Summary statistics of vehicular density at TIG locations

Location Code	TW			LV			HV			PT			Sample Size (N)
	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	
TIGN3	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIGN2	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIGN1	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIG0	264.0	53.7	302	1210.5	123.7	1298	880.5	0.7	881	2355.0	69.3	2404	2
TIGS1	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIGS2	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
TIGS3	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2

Table A.1.8 Summary statistics of vehicular density at H locations

Location Code	TW			LV			HV			PT			Sample Size (N)
	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	Mean	± SD	Max	
H1	1023.5	386.8	1297	3730.5	416.5	4025	1228.0	53.7	1266	5982.0	24.0	5999	2
H2	1155.0	507.7	1514	5570.0	2643.2	7439	1277.5	235.5	1444	8002.5	3386.3	10397	2

Table A.1.9. Summary statistics of vehicular density at IE locations													
Location Code	TW			LV			HV			ρ_T			Sample Size (N)
	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	
IE1	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	0.0	0.0	0	2
IE2	278.0	15.6	289.0	1827.5	23.3	1844	729.0	0.0	729	2834.5	7.8	2840	2

Table A.1.10. Summary statistics of vehicular density at A locations													
Location Code	TW			LV			HV			ρ_T			Sample Size (N)
	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	Mean	$\pm$ SD	Max	
A0	1419.5	186.0	1551	4941.5	688.0	5428	1351.0	29.7	1372	7712.0	531.7	8088	2
A1	1419.5	186.0	1551	4941.5	688.0	5428	1351.0	29.7	1372	7712.0	531.7	8088	2
A2	1196.0	89.1	1259	5417.5	1209.9	6273	1239.0	104.7	1313	7852.5	1403.6	8845	2
A3	1196.0	89.1	1259	5417.5	1209.9	6273	1239.0	104.7	1313	7852.5	1403.6	8845	2
A4	1043.0	14.1	1053	4832.5	638.5	5284	1248.5	34.6	1273	7124.0	618.0	7561	2
A5	1054.5	2.1	1056	4688.5	842.2	5284	1212.5	16.3	1224	6955.5	856.3	7561	2

APPENDIX

II

**Table A.2.1 Summary statistics of micro-meteorological conditions
at CB locations**

S No	Location Code	Nov 97-May 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)								
	CB1	11.3	3.9	16.1	8	24.5	0.6	25.4	8
	CB2	23.8	1.0	25.7	8	23.7	1.0	25.1	8
	CB3	20.7	0.3	21.0	8	23.1	0.8	24.1	5
2.	Relative Humidity (%)								
	CB1	83.8	1.0	85	8	68.6	2.6	72	8
	CB2	69.4	4.5	76	8	63.9	2.9	68	8
	CB3	78.1	2.4	81	8	65.4	2.4	68	5
3.	Wind Speed (km/hr)								
	CB1	5.5	3.5	12.2	8	8.5	2.2	11.1	8
	CB2	10.5	5.8	22.8	8	23.8	40.0	12.2	8
	CB3	10.5	5.8	22.8	8	19.7	13.1	29.1	5
4.	Wind Direction (° from N)								
	CB1	251.3	123.0	359.8	8	122.3	2.1	124.3	8
	CB2	121.3	1.5	123.1	8	207.7	5.4	216.5	8
	CB3	121.3	1.5	123.1	8	207.6	4.6	211.0	5

Table A.2.2 Summary statistics of micro-meteorological conditions at MP locations

S No	Location Code	Nov 97-May 98				Oct 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)												
	MP1	20.5	0.8	22.0	8	23.2	0.8	24.1	8	23.9	0.8	25.2	5
	MP2	19.9	0.8	20.9	8	23.2	0.8	24.1	8	23.7	0.4	24.2	5
	MP3	22.8	2.4	26.0	8	-	-	-	-	21.5	1.5	23.1	8
	MP4	21.9	1.3	23.8	8	-	-	-	-	21.5	1.5	23.1	8
	MP5	17.5	1.2	19.7	8	-	-	-	-	19.1	0.6	19.9	8
	MP6	24.5	2.2	27.0	8	21.6	0.6	22.6	8	21.0	1.9	23.4	8
	MP7	20.7	0.6	21.5	8	20.1	1.3	21.6	6	18.3	0.4	18.8	8
	MP8	18.0	1.6	21.1	8	20.8	1.0	22.4	8	14.9	0.7	15.8	8
	MP9	20.2	0.9	21.0	8	-	-	-	-	17.7	0.6	18.3	8
	MP10	23.0	1.6	24.5	8	-	-	-	-	17.0	0.7	17.8	8
	MP11	22.7	1.9	24.4	8	-	-	-	-	17.0	0.7	17.8	8
	MP12	18.8	3.1	25.8	8	-	-	-	-	21.5	1.5	23.1	8
	MP13	25.9	2.5	28.2	8	-	-	-	-	15.3	1.3	16.8	8
2.	Relative Humidity (%)												
	MP1	84.4	5.2	91.0	8	66.4	9.1	78.0	8	67.6	2.1	71.0	5
	MP2	87.1	3.4	90.0	8	66.4	9.1	78.0	8	67.6	2.1	71.0	5
	MP3	63.4	7.3	70.0	8	-	-	-	-	76.0	5.3	84.0	8
	MP4	70.4	6.1	77.0	8	-	-	-	-	76.0	5.3	84.0	8
	MP5	84.1	6.5	90.0	8	-	-	-	-	80.8	1.3	82.0	8
	MP6	38.5	9.1	51.0	8	65.3	3.1	69.0	8	65.5	5.8	74.0	8
	MP7	62.3	7.3	76.0	8	43.7	4.8	53.0	6	70.8	3.4	73.0	8
	MP8	65.3	15.2	86.0	8	58.9	10.8	77.0	7	67.1	1.6	69.0	8
	MP9	62.0	7.8	76.0	8	-	-	-	-	66.1	6.9	74.0	8
	MP10	66.4	6.6	77.0	8	-	-	-	-	45.3	8.3	58.0	8
	MP11	70.8	6.3	81.0	8	-	-	-	-	45.3	8.3	58.0	8
	MP12	73.6	14.5	90.0	8	-	-	-	-	76.0	5.3	84.0	8
	MP13	44.6	16.5	71.0	8	-	-	-	-	53.6	4.1	60.0	8

Table A.2.3 Summary statistics of micro-meteorological conditions at MP locations

S No	Location Code	Nov 97-May 98				Oct 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
3.	Wind Speed (km/hr)												
	MP1	4.7	2.8	10.1	8	4.3	1.0	5.2	8	6.0	3.4	10.6	5
	MP2	4.7	2.8	10.1	8	4.3	1.0	5.2	8	6.0	3.4	10.6	5
	MP3	7.9	1.4	9.7	8	-	-	-	-	11.8	0.7	12.5	8
	MP4	7.9	1.4	9.7	8	-	-	-	-	8.8	4.0	13.6	8
	MP5	7.3	4.7	14.5	8	-	-	-	-	5.1	2.5	8.8	8
	MP6	8.3	1.2	10.1	8	6.2	3.1	10.7	8	7.9	2.6	10.9	8
	MP7	7.1	0.9	8.5	8	6.0	2.1	8.5	6	7.4	2.0	9.2	8
	MP8	6.9	0.9	8.4	8	4.3	1.8	6.4	4	5.1	2.5	8.8	8
	MP9	4.4	2.9	9.6	8	-	-	-	-	5.1	2.5	8.8	8
	MP10	12.5	1.6	15.4	8	-	-	-	-	7.3	1.6	9.0	8
	MP11	12.5	1.6	15.4	8	-	-	-	-	7.3	1.6	9.0	8
	MP12	6.1	2.5	9.6	8	-	-	-	-	11.3	1.5	12.5	8
	MP13	15.5	3.3	21.6	8	-	-	-	-	5.2	2.2	7.9	8
4.	Wind Direction (° from N)												
	MP1	183.2	65.8	316.3	8	179.0	45.1	227.5	8	356.9	2.3	359.8	5
	MP2	183.2	65.8	316.3	8	179.0	45.1	227.5	8	356.9	2.3	359.8	5
	MP3	233.4	35.3	282.6	8	-	-	-	-	353.8	5.8	359.2	8
	MP4	233.4	35.3	282.6	8	-	-	-	-	96.0	59.9	197.7	8
	MP5	110.6	87.8	283.2	8	-	-	-	-	112.5	93.9	245.6	8
	MP6	204.7	94.8	342.6	8	274.0	44.9	359.8	8	82.6	106.6	344.3	8
	MP7	204.7	16.8	235.2	8	143.0	89.7	272.1	6	165.0	27.3	198.0	8
	MP8	213.5	24.9	254.3	8	288.0	76.1	359.8	7	206.9	81.9	335.9	8
	MP9	137.2	66.2	195.6	8	-	-	-	-	206.9	81.9	335.9	8
	MP10	119.7	14.7	138.2	8	-	-	-	-	258.4	49.0	302.2	8
	MP11	119.7	14.7	138.2	8	-	-	-	-	258.4	49.0	302.2	8
	MP12	56.0	106.3	279.0	8	-	-	-	-	353.8	5.8	359.2	8
	MP13	115.2	26.5	137.0	8	-	-	-	-	187.1	60.5	250.2	8

Table A.2.5 Summary statistics of micro-meteorological conditions at MU locations

S No	Location Code	Nov 97-May 98				Oct 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
3.	Wind Speed (km/hr)												
	MU1	4.9	1.7	7.5	8	-	-	-	-	5.1	2.5	8.8	8
	MU2	4.9	1.7	7.5	8	-	-	-	-	7.9	2.6	10.9	8
	MU3	14.2	2.8	16.6	8	6.7	2.7	10.0	8	7.9	3.4	11.4	8
	MU4	5.9	4.3	13.4	8	-	-	-	-	8.8	4.0	13.6	8
	MU5	5.9	4.3	13.4	8	-	-	-	-	4.8	1.2	6.4	8
	MU6	16.9	2.5	21.3	8	9.0	3.2	12.0	8	9.5	2.3	11.7	8
	MU7	15.5	3.3	21.6	8	9.1	1.9	11.9	8	6.4	2.5	9.4	8
	MU8	15.3	4.6	18.9	8	-	-	-	-	5.2	2.2	7.9	8
	MU9	15.4	4.7	18.9	8	-	-	-	-	10.0	2.0	13.0	8
	MU10	6.6	3.5	11.0	8	6.0	4.2	12.9	8	10.0	2.0	13.0	8
	MU11	6.6	3.5	11.0	8	6.7	3.4	10.2	8	6.6	3.1	10.9	8
4.	Wind Direction (° from N)												
	MU1	153.0	72.6	213.1	8	-	-	-	-	112.6	93.9	245.8	8
	MU2	153.0	72.6	213.1	8	-	-	-	-	82.6	106.6	344.3	8
	MU3	123.0	6.9	125.8	8	111.2	53.2	204.7	8	226.6	69.8	259.6	8
	MU4	97.9	52.9	151.5	8	-	-	-	-	96.0	59.9	197.7	8
	MU5	97.9	52.9	151.5	8	-	-	-	-	233.8	54.1	354.1	8
	MU6	116.2	17.0	132.0	8	67.3	13.6	88.1	8	193.2	94.7	254.5	8
	MU7	115.1	26.5	137.0	8	173.7	150.2	350.3	8	240.6	61.9	311.5	8
	MU8	97.4	27.9	144.6	8	-	-	-	-	158.8	77.3	250.1	8
	MU9	97.4	27.9	144.6	8	-	-	-	-	260.9	24.0	300.4	8
	MU10	110.0	54.4	173.3	8	168.9	86.1	345.5	8	260.9	24.0	300.4	8
	MU11	110.0	54.4	173.3	8	284.4	77.5	349.8	8	205.4	73.5	314.6	8

Table A.2.6 Summary statistics of micro-meteorological conditions at HP locations

S No	Location Code	Nov 97-May 98				Oct 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)												
	HP1	22.3	1.4	25.0	8	-	-	-	-	20.5	0.6	21.9	8
	HP2	18.2	1.6	21.3	8	-	-	-	-	19.6	1.1	20.8	8
	HP3	20.5	2.0	22.7	8	22.2	2.0	23.8	8	19.6	1.1	20.8	8
	HP4	23.9	1.2	25.0	8	24.5	1.4	25.6	5	15.2	1.1	17.1	8
	HP5	18.2	3.5	26.5	8	-	-	-	-	17.3	0.8	18.0	8
	HP6	19.4	1.2	21.2	8	24.1	2.1	26.2	8	17.6	1.6	19.1	8
	HP7	20.4	0.9	21.2	8	19.1	0.7	19.7	6	16.7	0.8	18.1	8
	HP8	17.4	1.5	19.1	8	19.1	0.7	19.7	6	18.9	1.8	21.0	8
	HP9	18.3	1.8	20.8	8	19.9	0.4	20.3	8	14.6	2.1	19.1	8
	HP10	23.4	1.7	25.5	8	-	-	-	-	15.2	3.3	20.3	8
	HP11	18.8	2.2	22.9	8	22.6	2.6	27.6	8	18.9	2.6	21.8	8
	HP12	18.3	1.2	19.8	8	21.6	2.4	25.0	8	14.4	1.9	17.2	8
	HP13	20.6	0.7	21.1	8	21.3	0.2	21.6	8	13.8	1.4	15.4	8
2.	Relative Humidity (%)												
	HP1	52.4	11.1	65.0	8	-	-	-	-	66.9	3.4	73.0	8
	HP2	66.0	7.4	73.0	8	-	-	-	-	43.3	8.0	57.0	8
	HP3	59.1	11.7	72.0	8	50.1	5.3	59.0	8	43.3	8.0	57.0	8
	HP4	56.6	9.3	77.0	8	46.4	1.5	48.0	5	61.5	6.4	69.0	8
	HP5	77.6	14.3	99.0	8	-	-	-	-	50.8	7.8	69.0	8
	HP6	80.3	8.7	93.0	8	55.6	6.1	69.0	8	55.5	8.0	72.0	8
	HP7	52.6	4.2	59.0	8	60.5	3.8	64.0	6	49.6	1.3	52.0	8
	HP8	72.3	8.5	83.0	8	60.5	3.8	64.0	6	36.8	14.5	60.0	8
	HP9	66.3	12.2	83.0	8	74.9	2.9	79.0	8	38.6	4.0	48.0	8
	HP10	45.8	10.8	62.0	5	-	-	-	-	33.6	6.7	40.0	8
	HP11	74.8	8.0	83.0	8	59.1	8.4	72.0	8	34.8	4.3	44.0	8
	HP12	70.0	7.8	80.0	8	62.3	10.3	76.0	8	53.8	10.1	69.0	8
	HP13	70.5	2.0	73.0	8	73.1	4.2	80.0	8	59.4	4.7	66.0	8

Table A.2.7 Summary statistics of micro-meteorological conditions at HP locations

S No	Location Code	Nov 97-May 98				Oct 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
3.	Wind Speed (km/hr)												
	HP1	6.7	1.9	8.5	8	-	-	-	-	7.3	3.0	11.2	8
	HP2	9.9	4.6	16.3	8	-	-	-	-	6.1	1.9	8.0	8
	HP3	6.9	1.0	8.4	8	11.7	3.1	17.9	8	8.1	1.9	8.0	8
	HP4	14.2	2.8	16.6	8	5.0	1.1	5.8	5	7.9	3.4	11.4	8
	HP5	6.1	1.6	8.2	8	-	-	-	-	4.8	1.2	6.4	8
	HP6	6.3	2.6	10.9	8	10.6	3.0	16.0	8	3.4	1.7	6.0	8
	HP7	7.9	4.3	15.4	8	6.7	2.7	10.5	6	7.4	4.6	16.5	8
	HP8	8.6	4.3	13.9	8	7.7	3.8	13.2	6	7.4	4.6	16.5	8
	HP9	5.5	2.3	8.5	8	11.9	6.4	18.3	8	4.5	2.2	8.0	8
	HP10	17.0	1.3	18.6	5	-	-	-	-	9.8	4.0	16.1	8
	HP11	11.1	3.1	17.8	8	6.7	3.4	10.2	8	8.9	3.7	14.2	8
	HP12	11.1	3.1	17.8	8	7.8	6.8	18.2	8	3.5	2.3	7.6	8
	HP13	4.2	1.3	6.6	8	6.1	2.5	9.8	8	4.2	2.5	7.6	8
4.	Wind Direction (° from N)												
	HP1	204.2	16.8	235.2	8	-	-	-	-	230.7	36.3	268.6	8
	HP2	119.5	17.4	149.4	8	-	-	-	-	185.8	52.9	224.7	8
	HP3	213.5	24.8	254.3	8	125.3	114.9	270.0	8	185.8	52.9	224.7	8
	HP4	123.0	6.9	128.5	8	286.0	158.4	359.7	5	226.6	69.9	259.6	8
	HP5	214.9	146.5	359.7	8	-	-	-	-	233.8	54.1	354.1	8
	HP6	163.9	30.1	204.2	8	233.4	85.8	297.0	8	204.4	81.0	288.8	8
	HP7	107.3	25.6	160.9	8	223.9	34.2	265.2	6	138.2	110.7	326.4	8
	HP8	196.4	32.4	224.9	8	223.9	34.2	265.2	6	138.2	110.7	326.4	8
	HP9	95.7	106.5	272.1	8	75.7	47.4	186.6	8	180.0	91.1	339.7	8
	HP10	126.3	4.5	132.0	5	-	-	-	-	146.9	65.6	203.0	8
	HP11	83.4	82.4	271.8	8	288.7	68.1	349.8	8	146.6	54.4	201.3	8
	HP12	83.4	82.4	271.8	8	141.6	110.1	349.8	8	208.3	63.2	276.6	8
	HP13	226.3	64.4	349.2	8	164.0	122.9	354.9	8	208.3	63.2	276.6	8

Table A.2.8 Summary statistics of micro-meteorological conditions at HU locations

S No	Location Code	Nov 97-May 98				Oct 98			Nov 98-May 99				
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)												
	HU1	23.2	1.8	25.4	8	-	-	-	-	20.4	0.3	21.3	8
	HU2	19.2	1.3	20.2	8	-	-	-	-	20.5	0.6	21.9	8
	HU3	24.7	1.9	28.5	8	-	-	-	-	17.3	0.3	17.9	8
	HU4	20.6	2.0	25.2	8	-	-	-	-	17.7	1.1	19.1	8
	HU5	20.3	1.4	21.9	8	22.7	1.9	26.7	8	18.7	1.2	20.0	8
	HU6	21.2	1.6	23.2	8	24.2	1.1	25.5	8	17.2	1.3	19.3	8
	HU7	22.9	1.4	25.6	8	21.3	2.0	24.1	8	16.6	1.2	18.0	8
	HU8	23.1	1.2	23.9	8	-	-	-	-	15.9	0.7	17.0	8
	HU9	23.6	1.3	25.0	8	20.1	0.4	20.6	8	13.9	1.3	15.8	8
	HU10	23.6	1.3	25.0	8	-	-	-	-	15.2	1.3	16.2	8
	HU11	23.8	2.0	26.8	8	-	-	-	-	13.1	1.6	16.8	8
2.	Relative Humidity (%)												
	HU1	45.8	9.6	62.0	8	-	-	-	-	66.4	3.2	72.0	8
	HU2	65.1	12.4	86.0	8	-	-	-	-	66.9	3.4	73.0	8
	HU3	53.8	10.1	72.0	8	-	-	-	-	80.4	4.5	86.0	8
	HU4	51.0	11.9	69.0	8	-	-	-	-	81.1	5.9	92.0	8
	HU5	61.5	10.8	80.0	8	56.9	5.1	62.0	8	69.6	2.1	73.0	8
	HU6	65.1	6.6	75.0	8	50.3	5.9	62.0	8	57.0	7.3	69.0	8
	HU7	84.3	4.6	90.0	8	60.0	6.1	73.0	8	48.8	9.7	70.0	8
	HU8	80.8	5.6	86.0	8	-	-	-	-	43.9	3.3	46.0	8
	HU9	60.9	6.2	68.0	8	73.5	10.0	87.0	8	46.8	6.5	57.0	8
	HU10	78.4	5.6	90.0	8	-	-	-	-	55.9	2.8	60.0	8
	HU11	76.0	7.9	85.0	8	-	-	-	-	59.6	3.3	65.0	8

Table A.2.9 Summary statistics of micro-meteorological conditions at HU locations

S No	Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99				
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)	Sample Size (N)		
3.	Wind Speed (km/hr)											
	HU1	8.3	1.2	10.1	8	-	-	-	7.3	3.0	11.2	8
	HU2	5.2	1.3	7.2	8	-	-	-	7.3	3.0	11.2	8
	HU3	6.7	1.9	8.5	8	-	-	-	5.2	2.1	8.5	8
	HU4	7.1	0.9	8.5	8	-	-	-	5.2	2.1	8.5	8
	HU5	9.9	4.6	16.3	8	7.1	1.4	10.1	7.4	2.0	9.2	8
	HU6	6.3	2.6	10.9	8	5.3	1.2	7.2	3.4	1.7	6.0	8
	HU7	8.9	1.7	11.3	8	10.6	3.0	16.0	7.3	3.0	11.2	8
	HU8	14.2	2.8	16.6	8	-	-	-	4.5	2.2	8.0	8
	HU9	6.1	2.3	8.5	8	6.3	2.5	10.6	9.8	4.0	16.1	8
	HU10	3.9	1.8	6.6	8	-	-	-	9.5	2.3	11.7	8
HU11	8.6	4.3	13.9	8	-	-	-	6.4	2.5	9.4	8	
4.	Wind Direction (° from N)											
	HU1	204.7	94.8	342.6	8	-	-	-	230.7	36.3	268.6	8
	HU2	136.3	184.4	359.7	8	-	-	-	230.7	36.3	268.6	8
	HU3	204.2	16.8	235.2	8	-	-	-	208.2	66.3	268.5	8
	HU4	204.2	16.8	235.2	8	-	-	-	208.2	66.3	268.5	8
	HU5	119.5	17.5	149.4	8	237.9	116.3	357.5	165.0	27.3	198.0	8
	HU6	163.9	30.1	204.2	8	358.1	3.2	359.7	204.4	81.0	288.8	8
	HU7	148.9	23.3	185.3	8	233.4	85.8	296.9	230.7	36.3	268.6	8
	HU8	123.0	6.9	128.5	8	-	-	-	180.0	91.1	339.7	8
	HU9	123.4	0.4	123.8	8	86.2	82.49	289.0	146.9	65.6	203.0	8
	HU10	218.6	73.2	349.2	8	-	-	-	193.2	94.7	254.5	8
HU11	116.3	22.6	160.4	8	-	-	-	240.6	81.9	311.5	8	

**Table A.2.10 Summary statistics of micro-meteorological conditions
at TIF locations**

S No	Location Code	Nov 97-May 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)								
	TIFN3	21.9	2.2	25.8	8	11.7	0.9	12.7	8
	TIFN2	23.8	0.5	24.3	8	16.1	1.8	18.6	8
	TIFN1	23.1	1.3	25.4	8	16.1	1.6	18.4	8
	TIF0	23.6	1.3	25.0	8	13.9	1.3	15.8	8
	TIFS1	20.9	1.4	23.1	8	13.4	1.0	15.8	8
	TIFS2	20.4	1.2	19.2	8	16.1	1.8	18.6	8
	TIFS3	19.9	0.8	20.7	8	11.2	0.5	12.0	8
2.	Relative Humidity (%)								
	TIFN3	78.6	3.5	84.0	8	50.9	0.4	51.0	8
	TIFN2	54.5	9.4	69.0	8	37.5	13.1	62.0	8
	TIFN1	70.8	6.6	77.0	8	37.6	4.5	45.0	8
	TIF0	78.4	5.6	90.0	8	46.8	6.5	57.0	8
	TIFS1	76.5	5.2	84.0	8	55.6	5.6	64.0	8
	TIFS2	70.1	6.2	80.0	8	37.5	13.2	62.0	8
	TIFS3	79.8	3.0	84.0	8	75.1	2.5	78.0	8
3.	Wind Speed (km/hr)								
	TIFN3	7.4	2.6	11.6	8	5.5	1.2	7.3	8
	TIFN2	8.6	2.2	11.5	8	8.4	2.5	13.0	8
	TIFN1	8.6	2.2	11.5	8	6.6	3.1	10.9	8
	TIF0	6.1	2.3	8.5	8	9.8	4.0	16.1	8
	TIFS1	11.9	6.2	21.2	8	8.6	3.1	10.9	8
	TIFS2	11.9	6.2	21.2	8	8.4	2.5	13.0	8
	TIFS3	7.4	2.6	11.6	8	6.2	1.1	7.3	8
4.	Wind Direction (° from N)								
	TIFN3	119.1	1.4	121.0	8	198.6	80.3	275.5	8
	TIFN2	121.9	1.5	123.9	8	245.5	87.2	344.7	8
	TIFN1	121.9	1.5	123.8	8	205.4	73.5	314.6	8
	TIF0	123.4	0.4	123.8	8	146.9	65.6	203.0	8
	TIFS1	121.9	1.2	123.3	8	205.4	73.5	314.6	8
	TIFS2	121.9	1.2	123.3	8	245.5	87.3	344.7	8
	TIFS3	119.1	1.4	121.0	8	193.6	82.2	275.5	8

**Table A.2.11 Summary statistics of micro-meteorological conditions
at TIB locations**

S No	Location Code	Nov 97-May 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)								
	TIBN3	24.8	1.5	26.4	8	13.9	1.1	15.3	8
	TIBN2	24.2	2.1	27.1	8	13.9	1.2	15.2	8
	TIBN1	22.4	3.5	30.0	8	11.6	3.3	15.3	8
	TIB0	17.4	1.5	19.1	8	18.9	1.7	21.0	8
	TIBS1	24.1	1.5	26.5	8	13.7	2.8	17.4	8
	TIBS2	18.6	0.3	19.3	8	13.1	1.1	14.2	8
	TIBS3	20.8	1.0	22.0	8	14.6	1.8	16.7	8
2.	Relative Humidity (%)								
	TIBN3	44.1	8.0	57.0	8	50.3	3.5	56.0	8
	TIBN2	68.8	7.6	82.0	8	40.6	8.8	61.0	8
	TIBN1	65.1	11.3	80.0	8	48.5	2.2	51.0	8
	TIB0	72.3	8.5	83.0	8	36.8	14.5	60.0	8
	TIBS1	63.5	8.6	79.0	8	55.0	5.0	62.0	8
	TIBS2	84.6	3.8	90.0	8	55.0	5.0	62.0	8
	TIBS3	87.5	1.9	89.0	8	52.1	9.9	71.0	8
3.	Wind Speed (km/hr)								
	TIBN3	12.2	1.7	14.2	8	8.8	5.8	19.9	8
	TIBN2	4.5	2.6	8.9	8	8.8	5.8	19.9	8
	TIBN1	4.5	2.6	8.9	8	7.5	2.2	11.0	8
	TIB0	5.1	2.2	10.4	8	7.4	4.6	16.5	8
	TIBS1	12.2	1.7	14.2	8	7.5	2.2	11.0	8
	TIBS2	3.1	2.1	5.8	8	3.3	1.8	5.6	8
	TIBS3	3.1	2.1	5.8	8	3.7	2.2	7.0	8
4.	Wind Direction (° from N)								
	TIBN3	121.9	0.7	122.6	8	166.3	46.4	219.4	8
	TIBN2	120.6	0.4	121.3	8	166.3	46.4	219.4	8
	TIBN1	120.6	0.4	121.3	8	257.7	56.7	357.7	8
	TIB0	121.4	0.3	121.8	8	138.2	110.7	326.4	8
	TIBS1	121.9	0.7	122.6	8	248.8	58.3	357.7	8
	TIBS2	120.9	0.4	121.2	8	164.1	69.5	220.2	8
	TIBS3	120.9	0.4	121.2	8	175.2	53.2	220.2	8

**Table A.2.12 Summary statistics of micro-meteorological conditions
at TIG locations**

S No	Location Code	Nov 97-May 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)								
	TIGN3	21.2	0.6	22.2	8	30.1	0.9	21.5	8
	TIGN2	22.3	1.0	23.9	8	19.9	1.0	21.5	8
	TIGN1	26.7	1.7	30.1	8	24.3	1.1	25.4	8
	TIG0	23.9	1.9	26.0	8	18.7	1.2	20.0	8
	TIGS1	22.7	1.0	23.9	8	23.4	2.1	26.8	8
	TIGS2	25.7	2.0	28.3	8	23.4	2.1	26.8	8
	TIGS3	24.6	0.8	25.7	8	24.4	1.0	25.4	8
2.	Relative Humidity (%)								
	TIGN3	79.9	7.1	90.0	8	73.4	7.8	83.0	8
	TIGN2	69.1	6.7	81.0	8	73.3	7.7	82.0	8
	TIGN1	58.3	2.1	62.0	8	57.8	7.7	70.0	8
	TIG0	72.9	7.9	84.0	8	69.6	2.1	73.0	8
	TIGS1	64.0	3.6	67.0	8	64.8	8.3	75.0	8
	TIGS2	43.5	9.2	62.0	8	64.8	8.3	75.0	8
	TIGS3	68.1	2.5	73.0	8	57.8	7.7	70.0	8
3.	Wind Speed (km/hr)								
	TIGN3	6.3	4.2	13.5	8	4.4	2.9	9.6	8
	TIGN2	6.3	4.2	13.5	8	4.4	2.9	9.6	8
	TIGN1	5.4	1.5	7.2	8	8.1	2.5	10.9	8
	TIG0	6.8	1.5	9.0	8	7.4	2.0	9.2	8
	TIGS1	6.6	1.7	8.5	8	6.4	2.0	8.4	8
	TIGS2	6.6	1.7	8.5	8	6.4	2.0	8.4	8
	TIGS3	5.4	1.5	7.2	8	8.1	2.5	10.9	8
4.	Wind Direction (° from N)								
	TIGN3	120.0	0.7	120.7	8	137.2	66.2	195.6	8
	TIGN2	120.0	0.7	120.7	8	137.2	66.2	195.6	8
	TIGN1	120.6	0.6	121.3	8	224.0	25.5	252.6	8
	TIG0	120.1	1.0	121.1	8	165.0	27.3	198.0	8
	TIGS1	120.9	0.6	121.5	8	206.7	38.4	254.3	8
	TIGS2	121.0	0.6	121.5	8	206.7	38.4	254.3	8
	TIGS3	120.6	0.6	121.3	8	224.0	25.5	252.6	8

Table A.2.13 Summary statistics of micro-meteorological conditions at H locations

S No	Location Code	Nov 97-May 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)								
	H1	23.6	1.3	25.0	8	16.3	1.5	17.9	8
	H2	22.2	0.7	22.9	8	12.7	1.4	15.0	8
2.	Relative Humidity (%)								
	H1	78.4	5.6	90.0	8	37.0	1.3	39.0	8
	H2	80.1	5.7	88.0	8	40.3	4.4	48.0	8
3.	Wind Speed (km/hr)								
	H1	4.3	3.4	8.0	8	6.4	2.9	11.8	8
	H2	9.2	2.7	12.6	8	15.3	3.8	22.6	8
4.	Wind Direction (° from N)								
	H1	118.2	10.4	123.1	8	172.9	54.3	234.1	8
	H2	120.1	1.5	121.3	8	120.9	13.0	130.6	8

Table A.2.14 Summary statistics of micro-meteorological conditions at IN locations

S No	Location Code	Nov 97-May 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)								
	IN1	20.4	1.1	21.6	8	15.9	2.0	18.0	8
	IN2	20.7	0.4	21.1	8	13.1	1.8	15.5	8
2.	Relative Humidity (%)								
	IN1	80.9	5.6	87.0	8	44.3	9.5	59.0	8
	IN2	78.5	3.9	81.0	8	45.3	6.8	56.0	8
3.	Wind Speed (km/hr)								
	IN1	-	-	-	-	-	-	-	-
	IN2	-	-	-	-	-	-	-	-
4.	Wind Direction (° from N)								
	IN1	-	-	-	-	-	-	-	-
	IN2	-	-	-	-	-	-	-	-

**Table A.2.15 Summary statistics of micro-meteorological conditions
at IE Locations**

S No	Location Code	Nov 97-May 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)								
	IE1	17.9	3.8	24.6	8	24.4	1.0	25.6	8
	IE2	25.4	1.9	26.8	8	24.6	1.1	25.6	8
2.	Relative Humidity (%)								
	IE1	71.0	7.0	84.0	8	60.3	5.9	68.0	8
	IE2	69.3	3.9	75.0	8	58.9	6.7	68.0	8
3.	Wind Speed (km/hr)								
	IE1	9.9	4.6	16.3	8	8.9	4.6	16.3	8
	IE2	9.9	4.6	16.3	8	8.9	4.6	16.3	8
4.	Wind Direction (° from N)								
	IE1	119.5	17.5	149.4	8	119.5	17.5	149.4	8
	IE 2	119.5	17.5	149.4	8	119.5	17.5	149.4	8

**Table A.2.16 Summary Statistics of Micro-Meteorological Conditions
at Altitude Locations**

S No	Location Code	Nov 97-May 98				Nov 98-May 99			
		Mean	± SD	Max	Sample Size (N)	Mean	± SD	Max	Sample Size (N)
1.	Amb Temp (°C)								
	A0	23.6	1.3	25.0	8	23.4	0.7	24.2	8
	A1	21.9	0.6	22.7	8	22.9	0.9	24.0	8
	A2	20.0	1.1	21.2	8	23.0	0.6	23.7	8
	A3	19.8	0.8	20.7	8	22.6	0.7	23.3	8
	A4	21.2	0.2	21.4	8	22.8	0.5	23.6	8
	A5	22.5	2.0	24.8	8	22.9	0.4	23.7	8
2.	Relative Humidity (%)								
	A0	78.4	5.6	90.0	8	69.0	2.0	72.0	8
	A1	77.8	4.5	85.0	8	66.8	1.7	69.0	8
	A2	78.0	3.2	84.0	8	68.6	2.8	72.0	8
	A3	76.6	4.1	84.0	8	66.0	2.6	69.0	8
	A4	72.3	5.1	78.0	8	69.8	2.4	72.0	8
	A5	75.3	5.4	82.0	8	70.5	2.7	75.0	8
3.	Wind Speed (km/hr)								
	A0	6.1	2.3	8.5	8	4.4	3.0	9.2	8
	A1	6.1	2.3	8.5	8	4.4	3.0	9.2	8
	A2	4.7	2.1	8.8	8	18.3	2.2	21.8	8
	A3	4.7	2.1	8.8	8	18.3	2.2	21.8	8
	A4	4.0	3.3	9.1	8	6.4	1.7	8.0	8
	A5	4.0	3.3	9.1	8	8.7	2.7	12.1	8
4.	Wind Direction (° from N)								
	A0	123.4	0.4	123.8	8	156.4	46.2	213.1	8
	A1	123.4	0.4	123.8	8	156.4	46.2	213.1	8
	A2	120.6	0.6	121.4	8	89.2	8.7	104.5	8
	A3	120.6	0.6	121.4	8	89.2	8.7	104.5	8
	A4	120.8	1.7	122.0	8	72.5	18.7	103.9	8
	A5	120.8	1.7	122.0	8	118.2	8.3	122.1	8

APPENDIX

III

**DATA SHEET FOR AIR-PARTICULATE SAMPLING UNDER
SCST & E. OF GOVT. OF MEGHALAYA SPONSORED RESEARCH PROJECT
ON**

"ASSESSMENT OF BREATHING LEVEL AIR QUALITY IN GREATER SHILLONG"

1.	Sample Code	06	Filter Code	05

2. Sampling Site : Bank Point (Near PHU Office)

3. Height from ground : 1.5 m

4. Distance from the road : 3 ft

5. DATA:

Time (hrs) :		9.15-10.15	10.15-11.15	11.15-12.15	12.15-1.15	1.15-2.15	2.15-3.15	3.15-4.15	4.15-5.15
Temp. (°C):		15.2	17.7	19.1	19.1	18.4	17.5	16.4	15.5
Humidity (%):		79.0	67.0	60.0	64.0	69.0	75.0	81.0	88.0
Traffic density	T.W.	95	95	90	100	120	105	85	90
	L.V.	420	590	850	515	585	515	560	605
	H.V.	85	65	90	65	100	80	90	120

6. Total Sampling Time : 8 hrs.

7. Traffic density : /min.

8. Ambient Temperature : 17.4 °C.

9. Average Humidity : 72.3 %.

10. Air-flow Rate : (i) Initial 15.0 l/min.

(ii) Final 15.0 l/min.

11. Volume of Air sampled : 7200 litres. = ... 7.2 m³.

12. Amt. of Particulate matter collected : 0.0014 g. TSP = 194.44 µg/m³

13. Colour of Particulate matter : Black.

14. Wind direction : Wind speed : 1.8 Km/hrs.

15. Pressure : mm/Hg

16. Weather condition: Clear sky/Cloudy/Partial cloudy.

17. Rain : (i) From hrs to hrs.

(ii) From hrs to hrs.

(iii) from hrs to hrs.

18. Total rainfall : 0 mm.

19. General Observations/Remarks: Weather was partially cloudy.
High Vehicular Movement.

Date : 19.11.97

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NEHU, SHILLONG - 793003

Table A.3.1 Protocol for sampling details-I

1. Place of sampling : Firbrigade Shilling H = Ground Floor
2. Date : 332 12 8 hrs 13 min 45 sec
3. Time : 23.80 (a) start : 8.55 AM (b) stop : 4.55 PM
4. Flow rate : 8.32 (a) Initial : 15 LPM (b) Final : 15 LPM
5. Relative humidity : 77% (a) RH — 73%
6. Ambient temperature : 21.2°C (b) Temp — 23.0°C
7. Weather conditions : clear/partially cloudy/cloudy/rainy/
8. Wind (a) speed : 47 m/min (b) direction :
9. Rain : 2.82 + 1.68 = 2.25 kms/hr.
10. Traffic Density : Altitude = 1560 m
Pressure = 1018 hpa.

A. Two Wheelers : $\frac{1}{2} \times 152 = 76$

B. Light Vehicles : 1 = 796

C. Heavy Vehicles :  = 139

Table A.3.2 Protocol for sampling details-II

Table A.3.3 Sampling dates and sample color at CB locations

Location Code	1 st Set		2 nd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour
CB1	10.11.97	Grey	17.05.99	Grey
CB2	10.05.98	Grey	25.04.99	Grey
CB3	10.05.98	Grey	25.04.99	Grey

Table A.3.4 Sampling dates and sample color at MP locations

Location Code	1 st Set		2 nd Set		3 rd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour	Sampling Date	Sample Colour
MP1	08.04.98	Black	20.11.98	Dark Grey	21.11.98	Dark Grey
MP2	08.04.98	Black	20.11.98	Dark Grey	21.11.98	Dark Grey
MP3	07.04.98	Black	-	-	26.11.98	Dark Grey
MP4	07.04.98	Dark Grey	-	-	25.11.98	Black
MP5	06.04.98	Black	-	-	27.11.98	Black
MP6	03.04.98	Black	-	-	30.11.98	Black
MP7	01.04.98	Black	19.11.98	Black	03.12.98	Black
MP8	26.03.98	Black	13.11.98	Dark Grey	09.12.98	Dark Grey
MP9	27.03.98	Dark Grey	10.11.98	Black	09.12.98	Dark Grey
MP10	09.04.98	Grey	-	-	14.12.98	Dark Grey
MP11	09.04.98	Dark Grey	-	-	14.12.98	Grey
MP12	26.11.97	Dark Grey	-	-	26.11.98	Dark Grey
MP13	14.04.98	Dark Grey	-	-	31.12.98	Black

Table A.3.5 Sampling dates and sample Color at MU locations

Location Code	1 st Set		2 nd Set		3 rd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour	Sampling Date	Sample Colour
MU1	04.04.98	Black	-	-	27.11.98	Black
MU2	04.04.98	Black	-	-	30.11.98	Black
MU3	10.04.98	Grey	09.11.98	Black	10.12.98	Black
MU4	20.04.98	Black	-	-	25.11.98	Black
MU5	20.04.98	Dark Grey	-	-	15.12.98	Dark Grey
MU6	13.04.98	Black	26.10.98	Black	28.12.98	Black
MU7	14.04.98	Black	27.10.98	Black	29.12.98	Black
MU8	15.04.98	Black	-	-	31.12.98	Black
MU9	15.04.98	Black	-	-	04.01.99	Black
MU10	16.04.98	Black	30.10.98	Black	04.01.99	Black
MU11	16.04.98	Black	29.10.98	Black	05.01.99	Dark Grey

Table A.3.6 Sampling dates and sample color at HP locations

Location Code	1 st Set		2 nd Set		3 rd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour	Sampling Date	Sample Colour
HP1	02.04.98	Black	-	-	01.12.98	Black
HP2	30.03.98	Black	-	-	08.12.98	Black
HP3	25.03.98	Black	16.11.98	Black	08.12.98	Black
HP4	10.04.98	Black	07.11.98	Black	10.12.98	Black
HP5	15.11.97	Dark Grey	-	-	15.12.98	Black
HP6	21.04.98	Dark Grey	03.11.98	Dark Grey	16.12.98	Grey
HP7	21.03.98	Dark Grey	02.11.98	Black	19.12.98	Black
HP8	19.11.97	Black	02.11.98	Dark Grey	19.12.98	Grey
HP9	13.11.97	Black	31.11.98	Black	21.12.98	Dark Grey
HP10	13.04.98	Dark Grey	-	-	23.12.98	Black
HP11	17.04.98	Black	28.10.98	Dark Grey	22.12.98	Dark Grey
HP12	17.04.98	Black	22.10.98	Dark Grey	02.01.99	Grey
HP13	18.04.98	Dark Grey	23.10.98	Black	02.01.99	Black

Table A.3.7 Sampling dates and sample color at HU locations

Location Code	1 st Set		2 nd Set		3 rd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour	Sampling Date	Sample Colour
HU1	03.04.98	Black	-	-	01.12.98	Black
HU2	07.11.97	Black	-	-	17.12.98	Black
HU3	02.04.98	Black	-	-	02.12.98	Black
HU4	01.04.98	Black	-	-	02.12.98	Black
HU5	30.08.98	Black	18.11.98	Black	03.12.98	Black
HU6	21.04.98	Black	07.11.98	Black	16.12.98	Black
HU7	22.04.98	Dark Grey	03.11.98	Dark Grey	17.12.98	Dark Grey
HU8	11.04.98	Black	-	-	21.12.98	Black
HU9	01.05.98	Black	24.10.98	Black	23.12.98	Black
HU10	28.04.98	Black	-	-	28.12.98	Black
HU11	19.03.98	Black	-	-	29.12.98	Black

Table A.3.8 Sampling dates and sample color at TIF locations

Location Code	1 st Set		2 nd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour
TIFN3	08.05.98	Grey	08.01.99	Grey
TIFN2	30.04.98	Grey	07.01.99	Grey
TIFN1	29.04.98	Grey	05.01.99	Grey
TIF0	01.05.98	Black	04.04.99	Black
TIFS2	29.04.98	Dark Grey	05.01.99	Grey
TIFS2	30.04.98	Grey	07.01.99	Grey
TIFS3	08.05.98	Grey	08.05.99	Grey

Table A.3.9 Sampling dates and sample color at TIB locations

Location Code	1 st Set		2 nd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour
TIBN3	Grey	09.05.98	13.01.99	Grey
TIBN2	Grey	07.05.98	12.01.99	Grey
TIBN1	Grey	06.05.98	11.01.99	Grey
TIB0	Dark Grey	11.05.98	10.01.99	Dark Grey
TIBS2	Grey	06.05.98	11.01.99	Grey
TIBS2	Grey	07.05.98	12.01.99	Grey
TIBS3	Grey	09.05.98	13.01.99	Grey

Table A.3.10 Sampling dates and sample color at TIG locations

Location Code	1 st Set		2 nd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour
TIGN3	15.05.98	Grey	23.04.99	Grey
TIGN2	14.05.98	Grey	22.04.99	Grey
TIGN1	13.05.98	Grey	21.04.99	Grey
TIG0	16.05.98	Black	20.04.98	Black
TIGS2	13.05.98	Grey	21.04.99	Grey
TIGS2	14.05.98	Grey	22.04.99	Grey
TIGS3	16.05.98	Grey	23.04.99	Grey

Table A.3.11 Sampling dates and sample color at H locations

Location Code	1 st Set		2 nd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour
H1	28.04.98	Black	15.01.99	Black
H2	05.05.98	Black	16.01.99	Black

Table A.3.12 Sampling dates and sample color at IN locations

Location Code	1 st Set		2 nd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour
IN1	28.04.98	Grey	15.01.99	Grey
IN2	05.05.98	Grey	16.01.99	Grey

Table A.3.13 Sampling dates and sample color at IE locations

Location Code	1 st Set		2 nd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour
IE1	21.11.97	Grey	24.04.99	Grey
IE2	11.05.98	Black	24.04.99	Black

Table A.3.14 Sampling dates and sample color at A locations

Location Code	1 st Set		2 nd Set	
	Sampling Date	Sample Colour	Sampling Date	Sample Colour
A0	01.05.98	Black	28.04.99	Black
A1	01.05.98	Dark Grey	28.04.99	Dark Grey
A2	02.05.98	Dark Grey	29.04.99	Dark Grey
A3	02.05.98	Dark Grey	29.04.99	Dark Grey
A4	04.05.98	Dark Grey	30.04.99	Dark Grey
A5	04.05.98	Dark Grey	01.05.99	Dark Grey

Table A.3.15 Summary statistics of TSP at MP locations (μgm^{-3})

Location Code	Mean	Max	$\pm$ SD	Sample Size (N)
MP1	106.4	139.9	34.1	3
MP2	146.7	164.2	27.8	3
MP3	190.5	206.4	22.4	2
MP4	235.5	262.7	38.5	2
MP5	373.9	400.6	37.8	2
MP6	267.8	295.7	39.5	2
MP7	268.2	433.6	158.9	3
MP8	478.2	657.1	197.3	3
MP9	354.1	571.7	199.0	3
MP10	330.3	444.0	160.8	2
MP11	180.8	254.0	103.5	2
MP12	362.5	391.6	41.2	2
MP13	292.0	301.7	13.8	2

**Table A.3.16 Summary statistics of TSP at MU locations
(μgm^{-3})**

Location Code	Mean	Max	$\pm$ SD	Sample Size (N)
MU1	363.6	458.3	134.0	2
MU2	354.5	417.3	88.8	2
MU3	476.9	597.2	125.3	3
MU4	334.2	375.0	57.7	2
MU5	120.5	149.9	41.6	2
MU6	355.0	426.8	69.8	3
MU7	411.8	470.4	61.8	3
MU8	397.4	405.0	10.8	2
MU9	417.1	445.4	40.0	2
MU10	496.4	530.8	45.8	3
MU11	373.4	295.7	33.9	3

**Table A.3.17 Summary statistics of TSP at HP locations
(μgm^{-3})**

Location Code	Mean	Max	$\pm$ SD	Sample Size (N)
HP1	197.6	228.5	43.7	2
HP2	424.0	459.8	50.6	2
HP3	314.9	361.1	48.6	3
HP4	249.9	375.0	109.1	3
HP5	169.5	172.4	4.1	2
HP6	214.1	277.8	71.9	3
HP7	426.0	502.1	71.9	3
HP8	197.2	216.5	18.1	3
HP9	491.7	508.3	18.1	3
HP10	489.2	494.8	7.9	2
HP11	246.4	333.3	85.6	3
HP12	347.8	371.0	26.1	3
HP13	281.6	373.6	79.9	3

Table A.3.18 Summary statistics of TSP at HU locations (μgm^{-3})

Location Code	Mean	Max	$\pm$ SD	Sample Size (N)
HU1	291.7	347.2	78.6	2
HU2	430.5	458.3	39.3	2
HU3	329.6	383.1	75.7	2
HU4	466.4	599.5	188.2	2
HU5	664.3	854.0	244.1	3
HU6	183.5	208.3	22.0	3
HU7	277.9	309.1	33.6	3
HU8	423.4	516.4	131.5	2
HU9	393.3	467.6	65.3	3
HU10	590.4	620.8	43.0	2
HU11	483.7	510.5	37.8	2

Table A.3.19 Summary statistics of oil-drops (OD) in suspended particulates at CB locations (in %)

Location Code	Mean	Max	$\pm$ SD	Sample Size (N)
CB1	12.9	15.6	3.9	2
CB2	17.1	19.9	4.0	2
CB3	14.9	19.7	6.8	2

Table A.3.20 Summary statistics of oil-drops (OD) in suspended particulates at MP locations (in %)

Location Code	Mean	Max	$\pm$ SD	Sample Size (N)
MP1	6.5	7.3	1.0	3
MP2	3.2	4.1	1.1	3
MP3	5.8	7.3	2.1	2
MP4	5.5	7.2	2.5	2
MP5	6.6	9.3	3.8	2
MP6	7.9	12.3	6.3	2
MP7	4.8	7.0	2.1	3
MP8	7.7	9.8	2.2	3
MP9	5.7	9.8	3.9	3
MP10	8.5	10.3	2.6	2
MP11	9.8	11.6	2.6	2
MP12	8.7	10.6	2.8	2
MP13	7.4	8.8	2.0	2

Table A.3.21 Summary statistics of oil-drops (OD) in suspended particulates at MU locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
MU1	7.4	9.3	2.8	2
MU2	7.0	9.6	3.8	2
MU3	7.2	12.4	4.6	3
MU4	4.1	4.3	0.4	2
MU5	5.9	8.6	3.9	2
MU6	4.5	7.1	2.3	3
MU7	5.4	8.8	3.0	3
MU8	6.7	9.7	4.3	2
MU9	7.3	10.7	4.8	2
MU10	3.9	6.3	2.6	3
MU11	5.0	6.9	1.8	3

Table A.3.22 Summary statistics of oil-drops (OD) in suspended particulates at HP locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
HP1	7.9	9.1	1.7	2
HP2	4.9	5.7	1.1	2
HP3	4.4	5.2	1.4	3
HP4	4.6	5.4	1.3	3
HP5	7.3	11.8	6.4	2
HP6	4.6	7.7	2.7	3
HP7	10.0	16.9	6.1	3
HP8	8.3	8.9	0.6	3
HP9	4.0	4.3	0.3	3
HP10	7.4	9.9	3.6	2
HP11	5.0	6.8	1.8	3
HP12	5.8	6.4	0.6	3
HP13	8.1	17.0	7.7	3

Table A.3.23 Summary statistics of oil-drops (OD) in suspended particulates at HU locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
HU1	5.5	8.0	3.6	2
HU2	4.6	6.0	2.0	2
HU3	3.5	6.2	3.8	2
HU4	5.8	8.5	3.9	2
HU5	3.8	5.5	1.7	3
HU6	3.0	5.9	2.5	3
HU7	8.5	19.6	9.6	3
HU8	3.8	5.4	2.3	2
HU9	5.9	7.0	1.4	3
HU10	8.5	13.7	7.4	2
HU11	10.0	12.7	3.9	2

Table A.3.24 Summary statistics of oil-drops (OD) in suspended particulates at TIF locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
TIFN3	12.3	17.9	8.0	2
TIFN2	6.3	6.4	0.1	2
TIFN1	8.7	11.5	4.0	2
TIF0	8.2	13.7	7.9	2
TIFS1	10.3	11.2	1.3	2
TIFS2	11.9	16.7	6.8	2
TIFS3	14.7	20.4	8.1	2

Table A.3.25 Summary statistics of oil-drops (OD) in suspended particulates at TIB locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
TIBN3	11.6	18.5	9.8	2
TIBN2	6.8	9.6	4.0	2
TIBN1	3.9	4.9	1.5	2
TIB0	7.2	10.7	5.0	2
TIBS1	10.3	17.3	9.9	2
TIBS2	7.7	8.1	0.6	2
TIBS3	5.9	8.9	4.2	2

Table A.3.26 Summary statistics of oil-drops (OD) in suspended particulates at TIG locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
TIGN3	12.8	15.4	3.7	2
TIGN2	14.0	20.2	8.8	2
TIGN1	13.5	16.3	4.0	2
TIG0	3.7	4.5	1.1	2
TIGS1	6.2	8.2	2.9	2
TIGS2	16.2	23.3	10.0	2
TIGS3	12.0	19.2	10.2	2

Table A.3.27 Summary statistics of oil-drops (OD) in suspended particulates at H locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
H1	4.1	6.0	2.8	2
H2	3.4	5.6	3.1	2

Table A.3.28 Summary statistics of oil-drops (OD) in suspended particulates at H locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
IN1	6.4	8.7	3.3	2
IN2	4.9	7.4	3.6	2

Table A.3.29 Summary statistics of oil-drops (OD) in suspended particulates at IE locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
IE1	14.6	24.8	14.5	2
IE2	2.1	2.6	0.7	2

Table A.3.30 Summary statistics of oil-drops (OD) in suspended particulates at A locations (in %)

Location Code	Mean	Max	± SD	Sample Size (N)
A0	10.4	13.7	4.7	2
A1	6.9	8.2	1.9	2
A2	5.8	8.0	3.1	2
A3	5.6	7.8	3.2	2
A4	3.7	5.3	2.3	2
A5	5.8	7.5	2.4	2

APPENDIX

IV

Table. A.4.1 Temporal variations in relative abundance (%) of PM_{2.5} at CB locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
CB1	8.9±8.8	15.1	20.6±8.6	26.6	18.2±8.0	23.8	11.4±5.4	15.2	2
CB2	21.1±9.5	27.8	16.2±3.0	18.3	13.9±2.6	15.7	7.6±3.0	9.7	2
CB3	18.9±11.9	27.2	14.9±1.3	15.8	17.5±1.3	18.4	8.5±0.4	8.7	2

Table. A.4.2 Temporal variations in relative abundance (%) of PM_{2.5} at MP locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
MP1	20.3±9.5	30.1	24.6±1.7	26.2	19.7±5.4	24.0	9.0±2.4	11.8	3
MP2	19.7±9.6	26.4	28.8±7.2	34.9	19.8±3.0	21.6	8.4±3.3	10.6	3
MP3	22.0±7.0	26.9	34.3±1.7	35.5	21.2±1.1	22.0	6.9±1.8	8.1	2
MP4	11.9±13.4	21.3	17.3±7.1	22.3	19.0±1.6	20.1	10.5±1.9	11.8	2
MP5	12.1±5.6	16.0	29.3±1.4	30.3	23.0±0.1	23.0	8.1±3.0	10.2	2
MP6	26.2±4.6	29.4	25.2±3.3	27.5	20.9±2.8	22.9	7.0±1.0	7.7	2
MP7	17.1±6.6	21.5	22.2±6.1	27.8	18.3±5.7	24.4	15.9±6.7	23.6	3
MP8	12.6±5.8	16.6	17.2±2.0	19.4	15.5±3.2	18.4	11.7±2.4	13.3	3
MP9	11.5±7.5	18.6	19.7±13.3	31.4	17.7±7.6	25.9	7.4±2.8	10.4	3
MP10	12.0±10.7	19.5	19.0±3.9	21.7	15.7±0.5	16.0	9.4±2.8	11.3	2
MP11	6.8±1.8	8.0	11.0±2.1	12.4	15.9±0.7	15.9	8.5±0.6	8.9	2
MP12	11.6±2.8	13.6	18.1±6.4	22.6	16.5±0.1	16.5	8.7±1.9	10.0	2
MP13	18.8±6.0	23.0	24.7±3.2	26.9	15.9±3.0	18.0	6.6±1.2	7.4	2

Table. A.4.3 Temporal variations in relative abundance (%) of PM_{2.5} at MU locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
MU1	17.0±1.0	17.7	32.5±3.8	36.2	14.2±4.4	17.3	11.0±3.5	13.4	2
MU2	30.1±4.7	33.4	28.9±5.2	32.6	14.0±6.7	18.7	7.5±0.5	7.8	2
MU3	12.0±8.4	19.4	18.1±2.3	20.5	15.8±0.7	16.4	7.7±2.1	9.9	3
MU4	18.9±6.1	23.2	27.2±0.9	27.8	13.9±1.0	14.6	8.4±3.0	10.5	2
MU5	19.7±0.3	19.9	12.2±0.4	12.5	16.5±0.1	16.5	9.8±0.4	10.0	2
MU6	27.0±13.6	42.3	22.3±4.6	27.5	19.2±1.5	20.1	9.2±3.8	13.2	3
MU7	21.2±6.9	28.3	21.4±4.3	24.7	16.7±3.0	20.1	7.3±1.6	9.1	3
MU8	16.8±0.1	16.6	24.0±11.0	31.7	16.8±1.3	17.7	8.8±0.6	9.2	2
MU9	21.3±1.2	22.1	24.4±8.49	30.4	15.1±3.3	17.4	8.2±0.1	8.2	2
MU10	21.3±11.4	34.4	25.0±9.0	34.5	20.8±3.4	23.3	10.2±1.8	12.2	3
MU11	19.8±6.6	27.4	24.2±2.5	26.9	17.2±1.9	19.4	11.6±0.4	11.9	3

Table. A.4. 4 Temporal variations in relative abundance (%) of PM_{2.5} at HP locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
HP1	20.9±0.1	21.0	25.2±1.3	26.1	20.3±1.6	21.4	10.2±1.0	10.9	2
HP2	20.5±4.5	23.7	25.9±3.3	28.2	19.4±4.5	22.6	9.9±1.0	10.6	2
HP3	22.2±11.4	32.8	22.9±4.7	25.6	19.3±3.0	22.3	8.4±3.2	12.1	3
HP4	18.9±10.0	29.4	19.8±1.3	20.9	18.3±1.9	20.5	9.1±2.4	10.8	3
HP5	21.5±1.1	22.3	23.8±4.6	27.9	25.2±1.1	25.9	8.5±1.4	9.5	2
HP6	17.9±8.4	27.0	22.7±10.1	34.1	20.7±11.0	33.0	8.1±2.5	10.9	3
HP7	27.3±19.4	49.4	24.4±5.8	30.8	17.2±4.6	21.1	7.3±1.7	9.2	3
HP8	16.9±4.9	22.6	21.9±5.8	26.1	18.0±7.1	23.9	9.6±4.2	13.5	3
HP9	29.3±15.0	46.1	23.2±6.1	29.2	19.6±3.3	23.1	6.9±4.8	12.3	3
HP10	21.6±11.1	29.4	24.4±1.3	25.3	17.8±3.7	20.4	8.5±0.4	8.7	2
HP11	25.4±1.6	26.8	24.7±1.9	26.9	16.8±1.7	18.7	8.3±1.7	10.1	3
HP12	19.8±3.0	22.8	24.3±7.5	31.6	22.4±4.4	27.1	9.2±2.6	11.5	3
HP13	21.2±3.6	24.5	22.0±7.6	28.9	25.2±4.1	29.9	9.7±1.5	11.3	3

Table. A.4.5 Temporal variations in relative abundance (%) of PM_{2.5} at HU locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	Mean ± SD	Max	
HU1	23.4±0.5	23.7	26.5±1.0	27.2	17.9±2.9	19.9	8.3±0.4	8.5	2
HU2	28.8±6.5	33.4	29.2±3.4	31.6	15.8±1.7	17.2	7.7±2.1	9.2	2
HU3	21.6±0.5	21.9	24.0±3.0	26.1	20.5±5.6	24.4	12.7±2.3	14.3	2
HU4	16.5±11.1	24.3	24.5±3.2	26.7	20.0±0.9	20.6	12.0±1.8	13.3	2
HU5	25.2±5.2	30.4	23.9±3.7	27.0	17.3±1.9	19.5	8.4±1.8	10.2	3
HU6	29.0±17.8	40.3	21.6±1.6	23.4	16.9±5.8	22.9	8.0±3.4	11.8	3
HU7	25.1±1.4	26.3	25.1±3.0	28.3	21.1±4.2	25.8	7.8±0.5	8.2	3
HU8	26.8±2.1	28.3	23.1±7.7	28.5	17.8±1.7	19.0	6.3±0.3	6.5	2
HU9	25.7±7.8	34.7	24.4±3.0	26.3	17.5±2.8	19.5	7.7±1.5	9.4	3
HU10	22.1±2.3	23.7	25.7±1.4	26.7	17.5±1.6	18.6	10.0±0.7	10.5	2
HU11	18.7±8.2	24.5	21.9±4.5	25.0	22.1±4.5	25.3	8.0±2.1	9.5	2

Table. A.4.6 Temporal variations in relative abundance (%) of PM_{2.5} at TIF locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIFN3	20.5 $\pm$ 5.8	24.6	21.1 $\pm$ 0.6	21.5	18.3 $\pm$ 1.4	19.3	11.1 $\pm$ 3.6	13.6	2
TIFN2	23.5 $\pm$ 4.8	26.9	24.1 $\pm$ 5.2	27.8	21.4 $\pm$ 1.5	22.4	6.9 $\pm$ 1.5	7.9	2
TIFN1	26.0 $\pm$ 0.6	26.4	28.8 $\pm$ 3.4	31.2	18.6 $\pm$ 5.0	22.1	7.0 $\pm$ 0.9	7.6	2
TIF0	30.7 $\pm$ 14.0	40.6	26.0 $\pm$ 1.8	27.3	15.0 $\pm$ 2.1	16.4	7.6 $\pm$ 2.7	9.5	2
TIFS1	25.5 $\pm$ 13.4	35.0	26.7 $\pm$ 0.6	27.1	12.0 $\pm$ 2.1	13.5	10.1 $\pm$ 4.0	12.9	2
TIFS2	27.1 $\pm$ 3.8	29.8	23.3 $\pm$ 6.7	28.0	19.2 $\pm$ 1.5	20.2	6.8 $\pm$ 0.6	7.2	2
TIFS3	29.8 $\pm$ 2.4	31.5	22.7 $\pm$ 6.3	27.1	18.7 $\pm$ 0.6	19.1	5.3 $\pm$ 1.8	6.6	2

Table. A.4.7 Temporal variations in relative abundance (%) of PM_{2.5} at TIB locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIBN3	25.5 $\pm$ 12.6	34.4	18.6 $\pm$ 9.6	25.4	17.9 $\pm$ 6.7	22.6	9.0 $\pm$ 2.6	10.8	2
TIBN2	22.8 $\pm$ 5.6	26.7	22.6 $\pm$ 2.8	24.5	16.3 $\pm$ 4.1	19.2	9.4 $\pm$ 1.1	10.1	2
TIBN1	20.7 $\pm$ 0.1	20.7	28.0 $\pm$ 1.2	28.8	18.9 $\pm$ 3.0	21.0	8.8 $\pm$ 1.6	9.9	2
TIB0	24.6 $\pm$ 14.9	35.1	17.8 $\pm$ 3.5	20.3	19.3 $\pm$ 3.8	22.0	12.7 $\pm$ 2.3	14.3	2
TIBS1	12.1 $\pm$ 10.6	19.5	19.6 $\pm$ 18.9	32.9	15.8 $\pm$ 5.2	19.5	10.9 $\pm$ 3.9	13.6	2
TIBS2	23.1 $\pm$ 0.8	23.6	25.9 $\pm$ 5.1	29.5	19.6 $\pm$ 2.9	21.6	10.5 $\pm$ 1.1	11.3	2
TIBS3	25.0 $\pm$ 1.2	25.8	26.8 $\pm$ 4.5	30.0	15.0 $\pm$ 0.8	15.5	7.1 $\pm$ 1.7	8.3	2

Table. A.4.8 Temporal variations in relative abundance (%) of PM_{2.5} at TIG locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIGN3	29.6 $\pm$ 5.2	33.3	27.7 $\pm$ 9.2	34.2	15.6 $\pm$ 0.4	15.8	6.9 $\pm$ 1.3	7.8	2
TIGN2	22.5 $\pm$ 0.2	22.6	21.0 $\pm$ 11.7	29.3	14.4 $\pm$ 2.4	16.1	6.8 $\pm$ 0.3	7.0	2
TIGN1	25.2 $\pm$ 10.7	32.7	20.6 $\pm$ 0.3	20.8	12.7 $\pm$ 1.4	13.7	6.6 $\pm$ 3.8	9.3	2
TIG0	32.5 $\pm$ 15.6	43.5	30.7 $\pm$ 4.0	33.5	14.5 $\pm$ 4.3	17.5	9.3 $\pm$ 5.2	12.9	2
TIGS1	23.9 $\pm$ 5.5	27.8	30.4 $\pm$ 0.6	30.8	15.9 $\pm$ 3.3	18.2	7.5 $\pm$ 2.7	9.4	2
TIGS2	29.0 $\pm$ 3.6	31.5	17.3 $\pm$ 4.8	20.7	14.1 $\pm$ 1.6	15.2	7.7 $\pm$ 5.3	11.4	2
TIGS3	20.6 $\pm$ 5.8	24.7	29.2 $\pm$ 2.3	30.8	14.9 $\pm$ 5.6	18.8	8.5 $\pm$ 2.9	10.5	2

Table. A.4.9 Temporal variations in relative abundance (%) of PM_{2.5} at H and IN locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
H1	27.8 $\pm$ 7.9	33.4	31.1 $\pm$ 0.7	31.6	19.0 $\pm$ 2.8	21.0	7.9 $\pm$ 2.3	9.5	2
H2	25.2 $\pm$ 4.7	28.5	25.2 $\pm$ 0.2	25.3	17.4 $\pm$ 2.7	19.3	8.2 $\pm$ 0.9	8.8	2
IN1	16.5 $\pm$ 10.4	23.8	18.6 $\pm$ 6.6	23.2	15.2 $\pm$ 1.8	16.5	7.2 $\pm$ 0.4	7.4	2
IN2	20.1 $\pm$ 1.3	21.0	24.1 $\pm$ 10.5	31.5	16.9 $\pm$ 0.6	17.3	7.7 $\pm$ 0.9	8.3	2

Table. A.4.10 Temporal variations in relative abundance (%) of PM_{2.5} at IE locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
IE1	12.0 $\pm$ 3.8	9.3	19.0 $\pm$ 13.7	28.7	21.3 $\pm$ 3.6	18.7	10.7 $\pm$ 0.4	10.9	2
IE2	30.0 $\pm$ 3.3	27.6	25.6 $\pm$ 0.8	26.1	18.6 $\pm$ 2.2	17.0	5.5 $\pm$ 2.3	7.1	2

Table. A.4.11 Temporal variations in relative abundance (%) of PM_{2.5} at A locations

Location Code	PM _{0.44}		PM _{0.88}		PM _{1.77}		PM _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
A0	19.9 $\pm$ 1.3	20.8	25.3 $\pm$ 0.9	25.9	17.6 $\pm$ 1.7	18.8	9.5 $\pm$ 0.1	9.5	2
A1	22.6 $\pm$ 9.6	29.3	28.3 $\pm$ 6.1	32.6	14.4 $\pm$ 0.6	14.8	6.5 $\pm$ 3.1	8.7	2
A2	19.8 $\pm$ 1.7	21.0	24.5 $\pm$ 2.1	26.0	16.3 $\pm$ 3.0	18.4	5.2 $\pm$ 3.2	7.4	2
A3	20.2 $\pm$ 4.0	23.0	27.9 $\pm$ 7.1	32.9	15.7 $\pm$ 0.0	15.7	7.3 $\pm$ 2.9	9.3	2
A4	27.0 $\pm$ 14.7	37.4	21.9 $\pm$ 3.5	24.3	15.6 $\pm$ 1.5	16.6	6.3 $\pm$ 3.5	8.8	2
A5	23.4 $\pm$ 1.3	24.3	36.1 $\pm$ 14.3	46.2	15.7 $\pm$ 5.2	19.3	6.4 $\pm$ 2.1	7.9	2

Table. A.4.12 Solid particle loadings at MP locations

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
MP1	0.89*	0.14	0.34	-0.04	0.12	0.95
MP2	0.91*	0.25	0.20	0.05	0.08	0.95
MP3	0.93*	0.25	0.12	0.07	0.02	0.96
MP4	0.25	0.17	0.92*	0.02	0.12	0.97
MP5	0.69	0.37	0.52	0.26	0.00	0.97
MP6	0.94*	0.11	0.09	-0.16	0.00	0.93
MP7	0.87	-0.09	0.26	0.33	0.16	0.97
MP8	0.19	0.36	0.61	0.01	0.66	0.99
MP9	0.24	0.94*	0.09	0.05	0.06	0.97
MP10	0.26	0.63	0.66	-0.07	0.09	0.93
MP11	-0.71*	0.55	0.29	-0.10	0.17	0.95
MP12	0.14	0.77*	0.55	-0.07	0.16	0.96
MP13	0.79*	0.39	0.29	-0.25	0.10	0.95
Eigen Values	8.03	3.06	0.86	0.27	0.26	
%Total Variance	61.82	23.56	6.67	2.12	2.00	
% Cumulative Variance	61.82	85.38	92.05	94.17	96.19	

* Significant Factor Loadings

Table. A.4.13 Solid particle loadings at MU locations

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
MU1	0.90*	0.28	-0.15	-0.04	0.25	0.97
MU2	0.91*	0.01	0.21	0.31	0.02	0.97
MU3	0.16	0.98*	0.11	0.01	0.02	0.99
MU4	0.83*	0.38	0.09	0.05	0.34	0.97
MU5	0.19	0.13	0.97*	0.01	0.01	0.99
MU6	0.90*	-0.01	0.37	0.08	-0.13	0.97
MU7	0.83*	0.33	0.34	0.16	0.01	0.94
MU8	0.83*	0.46	0.18	-0.12	0.17	0.96
MU9	0.89*	0.27	0.23	0.16	0.12	0.97
MU10	0.94*	0.14	0.19	-0.15	-0.11	0.96
MU11	0.96*	0.12	0.13	-0.09	0.05	
Eigen Values	8.22	1.07	1.03	0.19	0.15	
%Total Variance	74.76	9.72	9.37	1.70	1.33	
% Cumulative Variance	74.76	84.48	93.85	95.55	96.88	

* Significant Factor Loadings

Table. A.4.14 Solid particle loadings at HP locations

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
HP1	0.56	0.49	0.49	0.30	0.27	0.94
HP2	0.46	0.57	0.52	0.22	0.34	0.93
HP3	0.46	0.63	0.51	0.26	0.09	0.94
HP4	0.45	0.56	0.63	0.22	-0.04	0.93
HP5	0.72*	0.45	0.44	0.18	0.08	0.93
HP6	0.55	0.42	0.66	0.18	0.07	0.93
HP7	0.34	0.78*	0.35	0.33	0.09	0.93
HP8	0.43	0.35	0.74	0.30	0.14	0.92
HP9	0.38	0.84*	0.31	0.16	0.08	0.91
HP10	0.45	0.53	0.51	0.43	0.14	0.94
HP11	0.45	0.54	0.37	0.59	0.06	0.90
HP12	0.74*	0.35	0.41	0.32	0.15	0.92
HP13	0.82*	0.37	0.33	0.22	0.04	0.91
Eigen Values	11.56	0.47	0.27	0.19	0.11	
%Total Variance	88.89	3.66	2.05	1.43	0.88	
% Cumulative Variance	88.89	92.55	94.60	96.03	96.91	

* Significant Factor Loadings

Table. A.4.15 Solid particle loadings at HU locations

Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Communality
HU1	0.69	0.57	0.35	0.07	0.15	0.96
HU2	0.80*	0.50	0.21	0.07	0.12	0.96
HU3	0.56	0.73*	0.29	-0.21	0.02	0.98
HU4	0.38	0.83*	0.35	0.03	0.05	0.97
HU5	0.79*	0.48	0.29	0.03	-0.01	0.96
HU6	0.85*	0.33	0.30	-0.20	0.05	0.97
HU7	0.69	0.54	0.43	-0.01	-0.04	0.96
HU8	0.80*	0.34	0.43	-0.04	0.10	0.96
HU9	0.78*	0.46	0.34	0.00	0.06	0.95
HU10	0.64	0.58	0.35	-0.03	0.30	0.98
HU11	0.44	0.53	0.70*	-0.03	0.07	0.99
Eigen Values	9.90	0.43	0.18	0.10	0.07	
%Total Variance	90.00	3.92	1.71	0.95	0.69	
% Cumulative Variance	90.00	93.93	95.64	96.60	97.30	

* Significant Factor Loadings

Table A.4.16 Pearson correlation coefficients for pairwise comparisons of MP locations

Variable	MP1	MP2	MP3	MP4	MP5	MP6	MP7	MP8	MP9	MP10	MP11	MP12	MP13
MP1	1.00												
MP2	0.98*	1.00											
MP3	0.95*	0.99*	1.00										
MP4	0.61	0.50	0.42	1.00									
MP5	0.89*	0.90*	0.87*	0.76*	1.00								
MP6	0.95*	0.94*	0.94*	0.37	0.74	1.00							
MP7	0.90*	0.90*	0.89*	0.50	0.82*	0.29	1.00						
MP8	0.53	0.47	0.39	0.80*	0.63	0.29	0.41	1.00					
MP9	0.43	0.52	0.51	0.36	0.61	0.37	0.18	0.52	1.00				
MP10	0.53	0.58	0.53	0.81*	0.79*	0.38	0.35	0.80*	0.76*	1.00			
MP11	-0.44	-0.46	-0.51	0.24	-0.17	-0.57	-0.63	0.37	0.41	0.38	1.00		
MP12	0.47	0.48	0.42	0.73	0.69	0.30	0.21	0.80*	0.86*	0.96*	0.55	1.00	
MP13	0.92*	0.93*	0.91*	0.56	0.84*	0.87*	0.71	0.58	0.61	0.74	-0.25	0.65	1.00

• Significant correlation ($P < 0.05$)

Table A.4.17 Pearson correlation coefficients for pairwise comparisons of MU locations

Variable	MU1	MU2	MU3	MU4	MU5	MU6	MU7	MU8	MU9	MU10	MU11
MU1	1.00										
MU2	0.82*	1.00									
MU3	0.42	0.20	1.00								
MU4	0.82*	0.88*	0.51	1.00							
MU5	-0.08	-0.14	0.53	0.10	1.00						
MU6	0.75	0.95*	0.18	0.92*	0.02	1.00					
MU7	0.82*	0.89*	0.50	0.94*	0.25	0.92*	1.00				
MU8	0.90*	0.69	0.70	0.85*	0.34	0.69	0.86*	1.00			
MU9	0.90*	0.95*	0.46	0.94*	0.09	0.91*	0.97*	0.88*	1.00		
MU10	0.87*	0.89*	0.32	0.96*	0.03	0.95*	0.91*	0.84*	0.93*	1.00	
MU11	0.94*	0.92*	0.41	0.95*	-0.01	0.91*	0.92*	0.89*	0.97*	0.97*	1.00

* Significant correlation ($P < 0.05$)

Table A.4.18 Pearson correlation coefficients for pairwise comparisons of HP locations

Variable	HP1	HP2	HP3	HP4	HP5	HP6	HP7	HP8	HP9	HP10	HP11	HP12	HP13
HP1	1.00												
HP2	0.79*	1.00											
HP3	0.88*	0.90*	1.00										
HP4	0.82*	0.88*	0.99*	1.00									
HP5	0.73	0.89*	0.92*	0.92*	1.00								
HP6	0.75*	0.93*	0.96*	0.98*	0.96*	1.00							
HP7	0.86*	0.70	0.91*	0.88*	0.85*	0.81*	1.00						
HP8	0.57	0.92*	0.85*	0.88*	0.90*	0.95*	0.63	1.00					
HP9	0.92*	0.63	0.87*	0.84*	0.69	0.73	0.92*	0.49	1.00				
HP10	0.91*	0.95*	0.98*	0.96*	0.90*	0.95*	0.85*	0.84*	0.84*	1.00			
HP11	-0.24	-0.03	0.16	0.29	0.12	0.26	0.06	0.29	0.07	0.05	1.00		
HP12	0.65	0.95*	0.86*	0.88*	0.82*	0.93*	0.58	0.96*	0.55	0.89*	0.25	1.00	
HP13	0.82*	0.93*	0.98*	0.98*	0.88*	0.96*	0.82*	0.90*	0.79*	0.97*	0.21	0.93*	1.00

* Significant correlation ($P < 0.05$)

Table A.4.19 Pearson correlation coefficients for pairwise comparisons of HU locations

Variable	HU1	HU2	HU3	HU4	HU5	HU6	HU7	HU8	HU9	HU10	HU11
HU1	1.00										
HU2	0.98*	1.00									
HU3	0.90*	0.85*	1.00								
HU4	0.93*	0.85*	0.93*	1.00							
HU5	0.94*	0.98*	0.86*	0.80*	1.00						
HU6	0.92*	0.96*	0.83*	0.76*	0.99*	1.00					
HU7	0.95*	0.89*	0.91*	0.96*	0.85*	0.83*	1.00				
HU8	0.95*	0.95*	0.86*	0.82*	0.96*	0.96*	0.91*	1.00			
HU9	0.99*	0.98*	0.88*	0.88*	0.97*	0.86*	0.93*	0.99*	1.00		
HU10	0.97*	0.93*	0.91*	0.93*	0.88*	0.85*	0.95*	0.93*	0.95*	1.00	
HU11	0.87*	0.77*	0.89*	0.92*	0.75*	0.75	0.97*	0.87*	0.87*	0.90*	1.00

* Significant correlation ($P < 0.05$)

Table A.4.20 Variations in solid particle size distributions using optical microscope and image analysis system at CB1 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	Var	Micro	Image	± SD
PM _{0.44}	2.6	4.8	1.6	-	-	-	15.1	14.6	0.4
PM _{0.88}	14.5	12.0	1.8	-	-	-	26.6	30.6	2.8
PM _{1.77}	23.8	20.8	2.1	-	-	-	12.5	11.7	0.6
PM _{2.6}	15.2	17.0	1.3	-	-	-	7.6	7.6	0.0
Cum PM _{2.5}	56.1	54.6	1.1	-	-	-	61.8	64.5	1.9
PM ₅	28.1	30.4	1.6	-	-	-	15.8	14.6	0.8
PM ₁₀	11.6	10.6	0.7	-	-	-	12.6	13.3	0.5
PM _{>10}	4.3	4.3	0.0	-	-	-	9.8	7.7	1.5

Table A.4.21 Variations in solid particle size distributions using optical microscope and image analysis system at MP7 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	± SD	Micro	Image	± SD
PM _{0.44}	9.5	9.3	0.1	20.2	20.2	0.0	21.5	17.7	2.7
PM _{0.88}	23.2	18.9	3.0	15.7	16.1	0.3	27.8	21.6	4.4
PM _{1.77}	24.4	20.9	2.5	13.0	13.3	0.2	17.5	20.3	2.0
PM _{2.6}	11.2	17.1	4.2	23.6	24.4	0.6	12.9	17.1	3.0
Cum PM _{2.5}	68.3	66.2	1.5	72.5	74.0	1.1	79.7	76.7	2.1
PM ₅	13.2	15.4	1.6	15.0	12.9	1.5	9.3	9.5	0.1
PM ₁₀	11.6	12.3	0.5	8.1	8.4	0.2	6.6	7.6	0.7
PM _{>10}	6.9	6.1	0.6	4.4	4.7	0.2	4.4	6.2	1.3

Table A.4.22 Variations in solid particle size distributions using optical microscope and image analysis system at MP9 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	± SD	Micro	Image	± SD
PM _{0.44}	12.2	10.8	1.0	18.6	14.4	3.0	3.6	3.4	0.1
PM _{0.88}	31.4	30.6	0.6	22.4	18.8	2.5	5.2	5.6	0.3
PM _{1.77}	25.9	19.3	4.7	16.3	18.2	1.3	10.8	5.5	3.7
PM _{2.6}	10.4	15.9	3.9	6.9	16.5	6.8	4.9	10.8	4.2
Cum PM _{2.5}	79.9	76.6	2.3	64.2	67.9	2.6	24.5	25.3	0.6
PM ₅	9.1	7.8	0.9	11.8	15.7	2.8	17.9	26.1	5.8
PM ₁₀	5.5	6.8	0.9	11.1	7.8	2.3	32.0	20.2	8.3
PM _{>10}	5.4	8.8	2.4	12.9	8.6	3.0	25.6	28.4	2.0

Table A.4.23 Variations in solid particle size distributions using optical microscope and image analysis system at MU3 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	± SD	Micro	Image	± SD
PM _{0.44}	2.9	2.8	0.1	19.4	17.2	1.6	13.8	12.3	1.1
PM _{0.88}	15.9	13.6	1.6	20.5	21.4	0.6	17.8	12.5	3.7
PM _{1.77}	15.9	15.4	0.4	15.0	16.7	1.2	16.4	19.9	2.5
PM _{2.6}	9.9	13.9	2.8	7.6	7.8	0.1	5.7	6.3	0.4
Cum PM _{2.5}	44.6	45.7	0.8	62.5	63.1	0.4	53.7	51.0	1.9
PM ₅	22.4	23.3	0.6	15.0	15.8	0.6	14.6	16.4	1.3
PM ₁₀	18.1	18.7	0.4	12.5	8.3	3.0	16.2	16.4	0.1
PM _{>10}	14.9	12.3	1.8	10.0	12.8	2.0	15.4	16.2	0.6

Table A.4.24 Variations in solid particle size distributions using optical microscope and image analysis system at MU11 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	± SD	Micro	Image	± SD
PM _{0.44}	15.5	16.6	0.8	27.4	26.8	0.4	16.6	17.7	0.8
PM _{0.88}	26.9	25.6	0.9	23.8	21.8	1.4	21.9	17.1	3.4
PM _{1.77}	19.4	20.6	0.8	16.6	17.3	0.5	15.7	17.5	1.3
PM _{2.6}	11.9	14.9	2.1	11.1	12.7	1.1	11.7	9.9	1.3
Cum PM _{2.5}	73.7	77.7	2.8	78.9	78.6	0.2	65.9	62.2	2.6
PM ₅	14.2	12.5	1.2	10.1	13.7	2.5	14.5	12.4	1.5
PM ₁₀	7.5	6.4	0.8	6.6	2.8	2.7	11.8	13.9	1.5
PM _{>10}	4.3	3.4	0.8	4.6	4.9	0.2	7.9	11.5	2.5

Table A.4.25 Variations in solid particle size distributions using optical microscope and image analysis system at HP3 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	± SD	Micro	Image	± SD
PM _{0.44}	10.2	9.3	0.6	23.6	21.8	1.3	32.8	25.3	5.3
PM _{0.88}	17.5	16.8	0.5	25.5	26.9	1.0	25.6	20.6	3.5
PM _{1.77}	22.3	19.8	1.8	19.2	20.5	0.9	16.4	17.0	0.4
PM _{2.6}	12.1	12.3	0.1	7.1	5.2	1.3	6.1	18.8	9.0
Cum PM _{2.5}	62.1	58.2	2.8	75.4	74.4	0.7	80.9	81.7	0.6
PM ₅	18.2	19.4	0.8	12.4	13.4	0.7	11.4	8.2	2.3
PM ₁₀	13.8	13.0	0.6	8.2	8.3	0.1	4.4	4.4	0.0
PM _{>10}	5.8	9.4	2.5	4.1	3.9	0.1	3.3	5.7	1.7

Table A.4.26 Variations in solid particle size distributions using optical microscope and image analysis system at HP8 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	± SD	Micro	Image	± SD
PM _{0.44}	14.1	12.7	1.0	22.6	22.8	0.1	14.1	11.9	1.6
PM _{0.88}	24.2	20.3	2.8	26.1	23.5	1.8	15.3	17.3	1.4
PM _{1.77}	23.9	27.4	2.5	10.1	12.6	1.8	20.0	20.3	0.2
PM _{2.6}	10.2	10.7	0.4	5.1	7.3	1.6	13.5	15.3	1.3
Cum PM _{2.5}	72.4	71.1	0.9	63.9	66.2	1.6	62.9	64.8	1.3
PM ₅	13.2	21.5	5.9	16.9	16.4	0.4	15.2	14.1	0.8
PM ₁₀	8.4	5.3	2.2	11.4	11.7	0.2	13.0	10.2	2.0
PM _{>10}	6.0	2.1	2.8	7.8	5.7	1.5	8.9	11.1	1.6

Table A.4.27 Variations in solid particle size distributions using optical microscope and image analysis system at HU5 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	± SD	Micro	Image	± SD
PM _{0.44}	20.0	21.5	1.1	30.4	23.6	4.8	22.3	25.0	1.9
PM _{0.88}	19.8	20.2	0.3	25.0	23.3	1.2	27.0	24.8	1.6
PM _{1.77}	16.1	16.9	0.6	19.5	24.7	3.7	16.3	17.2	0.6
PM _{2.6}	8.1	8.7	0.4	10.2	13.6	2.4	8.4	8.5	0.1
Cum PM _{2.5}	64.0	67.3	2.3	85.1	85.2	0.1	74.0	75.5	1.1
PM ₅	16.1	16.8	0.5	6.4	7.8	1.0	10.3	9.1	0.8
PM ₁₀	12.9	9.9	2.1	6.1	4.8	0.9	9.5	9.4	0.1
PM _{>10}	7.0	6.0	0.7	2.4	2.2	0.1	6.2	6.0	0.1

Table A.4.28 Variations in solid particle size distributions using optical microscope and image analysis system at HU7 location (%)

Location Code	Nov 97-May 98			Oct 98			Nov 98-May 99		
	Micro	Image	± SD	Micro	Image	± SD	Micro	Image	± SD
PM _{0.44}	25.4	26.6	1.6	26.3	22.6	0.8	23.6	22.7	2.6
PM _{0.88}	28.3	24.7	1.4	24.7	24.8	2.5	22.4	19.0	0.1
PM _{1.77}	24.0	22.8	0.2	17.9	18.7	0.8	19.6	20.8	0.6
PM _{2.6}	7.9	8.9	1.3	8.2	8.3	0.7	7.3	8.2	0.1
Cum PM _{2.5}	85.6	83.0	1.3	77.1	74.4	1.8	72.9	70.7	1.9
PM ₅	8.7	10.5	0.8	12.7	13.8	1.3	10.3	12.7	0.8
PM ₁₀	3.7	3.5	2.0	6.8	7.8	0.1	9.6	5.5	0.7
PM _{>10}	2.0	3.0	1.6	3.4	4.0	0.7	7.2	11.1	0.4

**Table A.4.29 Summary statistics of solid particles characteristics
with image analysis system**

S No	Location Code	Mean	Min	Max	± SD	SE	2-S Range	Total Features
1.	CB1 Location							
	Length (μm)	5.16	0.88	46.02	4.47	0.12	17.86	1468
	Breadth (μm)	2.79	0.44	28.76	2.55	0.07	10.19	1468
	Area (μm ²)	12.12	0.78	503.56	24.67	0.64	98.67	1468
	Perimeter (μm)	16.64	3.54	479.65	23.08	0.60	92.31	1468
	Roundness	2.11	1.11	43.53	1.73	0.04	6.91	1468
	Feret's Dia (μm)	3.75	0.44	46.02	3.54	0.09	14.16	1468
2.	MP7 Location							
	Length (μm)	5.50	0.88	46.02	4.88	0.13	19.52	1392
	Breadth (μm)	2.97	0.44	36.73	2.81	0.08	11.26	1392
	Area (μm ²)	14.29	0.78	1010.26	34.67	0.93	138.69	1392
	Perimeter (μm)	17.74	3.54	259.29	20.57	0.55	82.28	1392
	Roundness	2.10	1.10	17.87	1.29	0.03	5.15	1392
	Feret's Dia (μm)	3.85	0.44	46.02	3.73	0.10	14.92	1392
3.	MU3 Location							
	Length (μm)	4.96	0.88	57.97	5.55	0.13	22.20	1790
	Breadth (μm)	2.68	0.44	38.05	3.35	0.08	13.39	1790
	Area (μm ²)	13.54	0.78	773.36	42.94	1.02	171.74	1790
	Perimeter (μm)	17.97	3.54	435.39	33.66	0.80	134.65	1790
	Roundness	2.38	1.14	36.64	2.33	0.06	9.32	1790
	Feret's Dia (μm)	4.08	0.44	57.97	5.07	0.12	20.29	1790
4.	HP3 Location							
	Length (μm)	5.02	0.88	67.26	5.50	0.14	22.00	1557
	Breadth (μm)	2.77	0.44	38.05	3.31	0.08	13.24	1557
	Area (μm ²)	14.29	0.78	973.45	48.64	1.23	194.56	1557
	Perimeter (μm)	17.67	3.54	50.265	30.30	0.77	121.21	1557
	Roundness	2.24	1.12	24.89	1.72	0.04	6.87	1557
	Feret's Dia (μm)	3.91	0.44	65.48	4.88	0.12	19.50	1557
5.	HU7 Location							
	Length (μm)	5.41	0.88	224.34	9.86	0.28	39.43	926
	Breadth (μm)	3.16	0.44	154.87	6.60	0.19	26.39	926
	Area (μm ²)	29.26	0.78	9493.50	289.72	8.24	1158.87	926
	Perimeter (μm)	27.63	3.54	5677.43	175.94	5.00	703.75	926
	Roundness	2.85	1.13	253.94	8.41	0.24	33.64	926
	Feret's Dia (μm)	4.46	0.44	205.75	8.82	0.25	35.31	926

Table A.4.30 Temporal variations in OD_{2.5} at CB locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
CB 1	0.9 $\pm$ 1.3	1.8	49.9 $\pm$ 10.2	57.1	34.9 $\pm$ 6.3	39.3	9.9 $\pm$ 8.8	16.1	2
CB 2	1.5 $\pm$ 0.7	2.0	52.8 $\pm$ 5.3	56.5	32.3 $\pm$ 4.4	35.4	9.8 $\pm$ 5.2	13.5	2
CB 3	11.8 $\pm$ 16.6	23.5	52.6 $\pm$ 0.4	52.9	25.0 $\pm$ 7.6	30.3	6.9 $\pm$ 4.2	9.8	2

Table A.4.31 Temporal variations in oil-drops of other size groups at CB locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
CB 1	95.5 $\pm$ 6.4	100.0	4.5 $\pm$ 6.4	9.0	0.0 $\pm$ 0.0	0.0	2
CB 2	96.4 $\pm$ 5.2	100.0	3.2 $\pm$ 4.5	6.3	0.5 $\pm$ 0.7	1.0	2
CB 3	96.2 $\pm$ 5.3	99.9	3.4 $\pm$ 4.8	6.8	0.4 $\pm$ 0.6	0.8	2

Table A.4.32 Temporal variations in OD_{2.5} at MP locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
MP1	0.0 $\pm$ 0.0	0.0	46.1 $\pm$ 14.3	62.5	43.5 $\pm$ 14.8	60.6	5.1 $\pm$ 4.7	10.5	3
MP2	0.0 $\pm$ 0.0	0.0	50.3 $\pm$ 24.0	66.7	31.5 $\pm$ 8.1	38.5	7.6 $\pm$ 13.1	22.7	3
MP3	7.5 $\pm$ 4.9	10.9	66.8 $\pm$ 4.0	69.6	16.5 $\pm$ 4.9	20.0	5.3 $\pm$ 1.8	6.5	2
MP4	1.2 $\pm$ 1.6	2.3	49.8 $\pm$ 11.2	57.7	40.2 $\pm$ 2.4	41.9	6.6 $\pm$ 3.9	9.3	2
MP5	6.8 $\pm$ 9.6	13.6	36.4 $\pm$ 19.3	50.0	46.0 $\pm$ 0.6	46.4	1.8 $\pm$ 2.5	3.6	2
MP6	4.5 $\pm$ 6.3	8.9	29.0 $\pm$ 4.1	31.9	41.3 $\pm$ 15.4	52.2	13.8 $\pm$ 1.1	14.5	2
MP7	3.1 $\pm$ 5.4	9.3	45.6 $\pm$ 15.6	57.1	39.6 $\pm$ 10.5	48.1	6.2 $\pm$ 10.7	18.6	3
MP8	1.2 $\pm$ 2.1	3.7	43.0 $\pm$ 14.8	51.7	42.1 $\pm$ 9.4	48.1	6.4 $\pm$ 4.8	11.1	3
MP9	6.4 $\pm$ 11.0	19.1	32.2 $\pm$ 18.3	52.9	49.9 $\pm$ 21.6	72.7	7.3 $\pm$ 6.6	12.8	3
MP10	0.0 $\pm$ 0.0	0.0	32.1 $\pm$ 30.5	53.6	45.2 $\pm$ 3.2	47.4	5.8 $\pm$ 3.0	7.9	2
MP11	0.0 $\pm$ 0.0	0.0	51.6 $\pm$ 4.2	54.5	42.8 $\pm$ 12.2	51.4	2.3 $\pm$ 3.2	4.5	2
MP12	2.8 $\pm$ 4.0	5.6	41.0 $\pm$ 16.1	52.4	33.4 $\pm$ 18.1	46.2	15.5 $\pm$ 1.0	16.2	2
MP13	2.8 $\pm$ 4.0	5.6	33.5 $\pm$ 1.3	34.4	44.8 $\pm$ 12.3	53.5	9.8 $\pm$ 5.9	14.0	2

Table A.4. 33 Temporal variations in oil-drops of other size groups at MP locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
MP1	94.7 $\pm$ 9.1	100.0	5.2 $\pm$ 9.1	15.7	0.0 $\pm$ 0.0	0.0	3
MP2	89.4 $\pm$ 18.4	100.0	10.6 $\pm$ 18.4	31.8	0.0 $\pm$ 0.0	0.0	3
MP3	96.0 $\pm$ 5.7	100.0	2.0 $\pm$ 2.8	4.0	0.0 $\pm$ 0.0	0.0	2
MP4	97.7 $\pm$ 3.3	100.0	2.3 $\pm$ 3.3	4.6	0.0 $\pm$ 0.0	0.0	2
MP5	90.9 $\pm$ 12.9	100.0	9.1 $\pm$ 12.9	18.2	0.0 $\pm$ 0.0	0.0	2
MP6	88.5 $\pm$ 4.0	91.3	10.8 $\pm$ 3.0	12.9	0.7 $\pm$ 1.0	1.4	2
MP7	94.6 $\pm$ 9.4	100.0	4.7 $\pm$ 8.1	14.0	0.8 $\pm$ 1.3	2.3	3
MP8	92.7 $\pm$ 6.4	100.0	6.1 $\pm$ 5.6	10.9	1.2 $\pm$ 2.1	3.7	3
MP9	95.7 $\pm$ 7.4	100.0	2.8 $\pm$ 4.9	8.5	2.1 $\pm$ 3.0	4.2	3
MP10	83.0 $\pm$ 24.3	100.0	17.1 $\pm$ 24.2	34.2	0.0 $\pm$ 0.0	0.0	2
MP11	96.6 $\pm$ 4.9	100.0	3.5 $\pm$ 4.9	6.9	0.0 $\pm$ 0.0	0.0	2
MP12	92.7 $\pm$ 4.9	96.2	7.3 $\pm$ 4.9	10.8	0.0 $\pm$ 0.0	0.0	2
MP13	93.1 $\pm$ 9.9	100.0	2.8 $\pm$ 4.0	5.6	4.2 $\pm$ 5.9	8.3	2

Table A.4.34 Temporal variations in OD_{2.5} at MU locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
MU 1	1.0 $\pm$ 1.4	2.0	28.3 $\pm$ 15.1	38.9	50.9 $\pm$ 2.7	52.8	16.9 $\pm$ 12.2	25.5	2
MU 2	13.6 $\pm$ 14.5	23.8	41.9 $\pm$ 21.5	57.1	25.4 $\pm$ 8.9	31.7	10.8 $\pm$ 15.3	21.6	2
MU 3	0.0 $\pm$ 0.0	0.0	36.6 $\pm$ 20.8	52.6	52.5 $\pm$ 22.4	78.3	8.6 $\pm$ 3.3	11.9	3
MU 4	2.0 $\pm$ 2.8	4.0	62.1 $\pm$ 19.7	76.0	26.4 $\pm$ 14.7	36.8	3.2 $\pm$ 4.5	6.4	2
MU 5	0.0 $\pm$ 0.0	0.0	47.0 $\pm$ 35.1	71.8	21.2 $\pm$ 6.3	25.6	12.4 $\pm$ 13.9	22.2	2
MU 6	0.0 $\pm$ 0.0	0.0	27.1 $\pm$ 14.6	43.8	52.8 $\pm$ 16.8	70.8	9.0 $\pm$ 6.7	16.7	3
MU 7	3.3 $\pm$ 5.8	10.0	47.6 $\pm$ 4.1	50.0	38.4 $\pm$ 10.1	50.0	9.5 $\pm$ 7.7	18.2	3
MU 8	0.0 $\pm$ 0.0	0.0	42.1 $\pm$ 31.3	64.2	49.9 $\pm$ 19.9	64.0	8.0 $\pm$ 11.3	16.0	2
MU 9	3.4 $\pm$ 4.8	6.8	30.4 $\pm$ 11.9	38.8	37.7 $\pm$ 14.9	48.2	18.4 $\pm$ 7.6	23.7	2
MU 10	0.0 $\pm$ 0.0	0.0	32.0 $\pm$ 7.6	40.7	47.2 $\pm$ 24.7	71.4	9.4 $\pm$ 8.7	17.1	3
MU 11	5.6 $\pm$ 3.0	8.3	47.8 $\pm$ 11.7	60.5	38.7 $\pm$ 9.2	48.4	6.5 $\pm$ 6.3	12.5	3

Table A.4. 35 Temporal variations in oil-drops of other size groups at MU locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
MU 1	97.1 $\pm$ 4.2	94.1	3.0 $\pm$ 4.2	5.9	0.0 $\pm$ 0.0	0.0	2
MU 2	91.7 $\pm$ 11.8	83.3	8.4 $\pm$ 11.8	16.7	0.0 $\pm$ 0.0	0.0	2
MU 3	97.7 $\pm$ 3.9	93.2	2.3 $\pm$ 3.9	6.8	0.0 $\pm$ 0.0	0.0	3
MU 4	93.7 $\pm$ 3.3	91.4	6.3 $\pm$ 3.3	8.6	0.0 $\pm$ 0.0	0.0	2
MU 5	80.6 $\pm$ 27.5	61.1	13.9 $\pm$ 19.7	27.8	5.6 $\pm$ 7.8	11.1	2
MU 6	88.9 $\pm$ 15.7	70.9	9.0 $\pm$ 12.1	22.8	2.1 $\pm$ 3.6	6.3	3
MU 7	98.9 $\pm$ 2.0	96.6	0.6 $\pm$ 1.0	1.7	0.6 $\pm$ 1.0	1.7	3
MU 8	100.0 $\pm$ 0.0	100.0	0.0 $\pm$ 0.0	0.0	0.0 $\pm$ 0.0	0.0	2
MU 9	89.8 $\pm$ 14.4	79.6	8.5 $\pm$ 12.0	17.0	1.7 $\pm$ 2.4	3.4	2
MU 10	89.0 $\pm$ 19.1	66.9	9.7 $\pm$ 16.9	29.2	1.6 $\pm$ 2.6	4.8	3
MU 11	98.6 $\pm$ 2.4	95.8	5.4 $\pm$ 6.1	12.0	0.0 $\pm$ 0.0	0.0	3

Table A.4.36 Temporal variations in OD_{2.5} at HP locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
HP1	28.0 $\pm$ 27.4	47.1	41.3 $\pm$ 8.2	47.1	13.2 $\pm$ 10.5	20.6	11.8 $\pm$ 16.6	23.5	2
HP2	1.8 $\pm$ 2.5	3.6	40.1 $\pm$ 6.2	44.4	42.0 $\pm$ 14.0	51.9	10.8 $\pm$ 10.0	17.8	2
HP3	3.3 $\pm$ 5.7	9.8	50.3 $\pm$ 24.7	76.5	38.2 $\pm$ 13.5	50.0	6.2 $\pm$ 8.3	15.6	3
HP4	0.0 $\pm$ 0.0	0.0	46.5 $\pm$ 15.0	62.1	39.6 $\pm$ 14.7	55.0	7.5 $\pm$ 13.0	22.6	3
HP5	1.2 $\pm$ 1.7	2.4	34.0 $\pm$ 15.6	45.0	42.5 $\pm$ 10.6	50.0	9.2 $\pm$ 5.9	13.3	2
HP6	19.0 $\pm$ 29.2	52.6	41.7 $\pm$ 5.3	47.4	34.5 $\pm$ 20.8	47.4	4.8 $\pm$ 4.6	9.1	3
HP7	3.3 $\pm$ 2.9	5.4	44.3 $\pm$ 1.7	46.2	46.7 $\pm$ 1.8	48.7	5.7 $\pm$ 0.8	6.6	3
HP8	0.0 $\pm$ 0.0	0.0	49.9 $\pm$ 20.9	71.9	34.7 $\pm$ 9.5	45.6	7.4 $\pm$ 7.6	15.2	3
HP9	6.2 $\pm$ 10.7	18.5	39.7 $\pm$ 31.5	67.7	21.7 $\pm$ 21.2	45.8	2.8 $\pm$ 4.8	8.3	3
HP10	2.3 $\pm$ 3.2	4.5	32.5 $\pm$ 4.2	35.5	41.1 $\pm$ 19.4	54.8	14.0 $\pm$ 6.0	18.2	2
HP11	1.8 $\pm$ 1.6	3.0	34.5 $\pm$ 6.4	41.9	58.3 $\pm$ 16.3	68.7	2.3 $\pm$ 4.0	7.0	3
HP12	0.0 $\pm$ 0.0	0.0	41.6 $\pm$ 20.6	59.4	45.3 $\pm$ 29.1	73.8	8.4 $\pm$ 6.3	15.6	3
HP13	1.9 $\pm$ 2.6	4.8	40.8 $\pm$ 22.6	59.4	45.4 $\pm$ 20.6	69.2	10.0 $\pm$ 5.2	15.4	3

Table A.4. 37 Temporal variations in oil-drops of other size groups at HP locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
HP1	94.2 $\pm$ 8.1	99.9	4.4 $\pm$ 6.2	8.7	1.5 $\pm$ 2.1	2.9	2
HP2	94.6 $\pm$ 7.6	100.0	3.6 $\pm$ 5.1	7.2	1.8 $\pm$ 2.5	3.6	2
HP3	98.0 $\pm$ 3.4	100.0	2.0 $\pm$ 3.4	5.9	0.0 $\pm$ 0.0	0.0	3
HP4	93.6 $\pm$ 11.1	100.0	6.4 $\pm$ 11.1	19.3	0.0 $\pm$ 0.0	0.0	3
HP5	86.8 $\pm$ 18.7	100.0	9.8 $\pm$ 13.6	19.2	3.6 $\pm$ 5.1	7.2	2
HP6	100.0 $\pm$ 0.1	100.0	0.0 $\pm$ 0.0	0.0	0.0 $\pm$ 0.0	0.0	3
HP7	100.0 $\pm$ 0.0	100.0	0.0 $\pm$ 0.0	0.0	0.0 $\pm$ 0.0	0.0	3
HP8	92.0 $\pm$ 13.9	100.0	6.5 $\pm$ 11.3	19.5	1.5 $\pm$ 2.5	4.4	3
HP9	70.4 $\pm$ 51.2	100.0	2.6 $\pm$ 9.7	16.8	24.0 $\pm$ 41.6	72.0	3
HP10	89.8 $\pm$ 14.5	100.0	8.0 $\pm$ 11.2	15.9	3.22.3 $\pm$	4.5	2
HP11	96.9 $\pm$ 5.4	100.0	3.1 $\pm$ 5.4	9.3	0.00.0 $\pm$	0.0	3
HP12	95.3 $\pm$ 4.1	97.7	4.7 $\pm$ 4.1	9.4	0.0 $\pm$ 0.0	0.0	3
HP13	98.1 $\pm$ 2.5	100.0	1.9 $\pm$ 2.6	4.8	0.0 $\pm$ 0.0	0.0	3

Table A.4.38 Temporal variations in OD_{2.5} at HU locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
HU 1	5.5 $\pm$ 7.7	10.9	35.3 $\pm$ 6.6	41.4	42.1 $\pm$ 28.8	62.5	8.6 $\pm$ 6.2	13.0	2
HU 2	2.9 $\pm$ 4.1	5.8	31.1 $\pm$ 0.7	31.6	48.2 $\pm$ 8.8	54.4	11.6 $\pm$ 2.8	13.5	2
HU 3	1.3 $\pm$ 1.8	2.6	40.6 $\pm$ 27.5	60.0	35.0 $\pm$ 21.2	50.0	17.9 $\pm$ 3.0	20.0	2
HU 4	8.0 $\pm$ 11.3	16.0	36.5 $\pm$ 7.9	42.1	38.1 $\pm$ 20.6	52.6	10.7 $\pm$ 7.6	16.0	2
HU 5	7.4 $\pm$ 12.8	22.2	45.1 $\pm$ 2.6	48.0	41.3 $\pm$ 23.1	57.1	1.2 $\pm$ 2.1	3.7	3
HU 6	4.5 $\pm$ 5.9	11.1	26.9 $\pm$ 11.1	33.3	51.7 $\pm$ 6.7	55.6	8.4 $\pm$ 7.4	14.0	3
HU 7	0.0 $\pm$ 0.0	0.0	51.0 $\pm$ 14.5	67.7	42.9 $\pm$ 18.3	58.3	3.6 $\pm$ 3.3	6.5	3
HU 8	0.0 $\pm$ 0.0	0.0	41.6 $\pm$ 38.5	68.8	31.3 $\pm$ 0.1	31.4	8.6 $\pm$ 12.1	17.1	2
HU 9	2.1 $\pm$ 3.6	6.3	61.5 $\pm$ 7.7	68.6	31.0 $\pm$ 12.4	43.3	4.7 $\pm$ 5.5	10.8	3
HU 10	0.0 $\pm$ 0.0	0.0	41.3 $\pm$ 4.5	44.4	41.9 $\pm$ 8.1	47.6	10.0 $\pm$ 6.2	14.3	2
HU 11	5.6 $\pm$ 3.8	8.3	45.0 $\pm$ 7.1	50.0	40.2 $\pm$ 3.8	42.9	7.8 $\pm$ 5.1	11.4	2

Table A.4.39 Temporal variations in oil-drops of other size groups at HU locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
HU 1	91.5 $\pm$ 6.3	95.9	8.6 $\pm$ 6.2	13.0	0.0 $\pm$ 0.0	0.0	2
HU 2	93.7 $\pm$ 1.3	94.6	6.3 $\pm$ 1.2	7.1	0.0 $\pm$ 0.0	0.0	2
HU 3	94.8 $\pm$ 7.4	100.0	5.3 $\pm$ 7.4	10.5	0.0 $\pm$ 0.0	0.0	2
HU 4	93.2 $\pm$ 9.6	100.0	6.2 $\pm$ 8.8	12.4	0.6 $\pm$ 0.8	1.2	2
HU 5	95.0 $\pm$ 8.6	100.0	3.7 $\pm$ 6.4	11.1	1.2 $\pm$ 2.1	3.7	3
HU 6	91.4 $\pm$ 14.8	100.0	7.0 $\pm$ 12.1	21.0	1.6 $\pm$ 2.7	4.7	3
HU 7	97.5 $\pm$ 2.3	100.0	1.4 $\pm$ 2.5	4.3	1.1 $\pm$ 1.8	3.2	3
HU 8	81.4 $\pm$ 26.3	100.0	18.6 $\pm$ 26.2	37.1	0.0 $\pm$ 0.0	0.0	2
HU 9	99.3 $\pm$ 1.1	100.0	0.7 $\pm$ 1.2	2.0	0.0 $\pm$ 0.0	0.0	3
HU 10	93.1 $\pm$ 9.8	100.0	2.8 $\pm$ 4.0	5.6	4.2 $\pm$ 5.9	8.3	2
HU 11	98.6 $\pm$ 2.0	100.0	1.5 $\pm$ 2.1	2.9	0.0 $\pm$ 0.0	0.0	2

Table A.4.40 Temporal variations in OD_{2.5} at TIF locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIFN3	1.3 $\pm$ 1.8	2.5	54.7 $\pm$ 13.9	64.5	37.9 $\pm$ 24.3	55.1	0.9 $\pm$ 1.2	1.7	2
TIFN2	0.0 $\pm$ 0.0	0.0	55.3 $\pm$ 33.4	78.9	24.6 $\pm$ 10.0	31.6	9.7 $\pm$ 8.7	15.8	2
TIFN1	3.6 $\pm$ 5.0	7.1	61.1 $\pm$ 1.1	61.9	27.1 $\pm$ 1.2	27.9	4.2 $\pm$ 2.5	5.9	2
TIF0	5.6 $\pm$ 7.8	11.1	62.1 $\pm$ 9.2	68.6	26.0 $\pm$ 10.4	33.3	5.4 $\pm$ 7.6	10.8	2
TIFS1	6.8 $\pm$ 9.5	13.5	55.0 $\pm$ 14.1	64.9	31.5 $\pm$ 21.6	46.7	5.2 $\pm$ 0.3	5.4	2
TIFS2	2.8 $\pm$ 2.8	4.8	67.9 $\pm$ 11.8	76.2	21.0 $\pm$ 0.6	21.4	5.6 $\pm$ 5.6	9.5	2
TIFS3	2.0 $\pm$ 1.9	3.3	76.5 $\pm$ 12.4	85.2	17.1 $\pm$ 7.8	22.6	2.9 $\pm$ 4.1	5.8	2

Table A.4.41 Temporal variations in oil-drops of other size groups at TIF locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIFN3	94.7 $\pm$ 7.5	100.0	5.0 $\pm$ 7.0	9.9	0.4 $\pm$ 0.6	0.8	2
TIFN2	89.5 $\pm$ 14.8	100.0	9.2 $\pm$ 13.0	18.4	1.3 $\pm$ 1.8	2.6	2
TIFN1	92.55.9 $\pm$	97.6	3.4 $\pm$ 1.4	4.4	0.8 $\pm$ 1.1	1.5	2
TIF0	99.01.4 $\pm$	100.0	1.0 $\pm$ 1.4	2.0	0.0 $\pm$ 0.0	0.0	2
TIFS1	98.4 $\pm$ 2.3	100.0	1.7 $\pm$ 2.3	3.3	0.0 $\pm$ 0.0	0.0	2
TIFS2	97.2 $\pm$ 2.8	99.1	2.8 $\pm$ 2.8	4.8	0.0 $\pm$ 0.0	0.0	2
TIFS3	98.4 $\pm$ 2.3	100.0	1.6 $\pm$ 2.3	3.2	0.0 $\pm$ 0.0	0.0	2

Table A.4.42 Temporal variations in OD_{2.5} at TIB locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIBN3	0.0 $\pm$ 0.0	0.0	54.9 $\pm$ 20.2	69.1	39.7 $\pm$ 14.6	50.0	5.1 $\pm$ 6.1	9.4	2
TIBN2	0.0 $\pm$ 0.0	0.0	48.4 $\pm$ 23.1	64.7	45.1 $\pm$ 32.5	68.0	5.2 $\pm$ 7.3	10.3	2
TIBN1	0.0 $\pm$ 0.0	0.0	27.9 $\pm$ 22.5	43.8	63.9 $\pm$ 28.4	84.0	3.6 $\pm$ 0.6	4.0	2
TIB0	0.0 $\pm$ 0.0	0.0	53.6 $\pm$ 13.5	63.1	36.8 $\pm$ 21.6	52.0	8.9 $\pm$ 6.9	13.8	2
TIBS1	0.0 $\pm$ 0.0	0.0	50.6 $\pm$ 26.9	69.6	41.5 $\pm$ 15.7	52.6	4.4 $\pm$ 6.2	8.8	2
TIBS2	0.0 $\pm$ 0.0	0.0	40.4 $\pm$ 6.6	45.1	51.3 $\pm$ 5.2	54.9	3.6 $\pm$ 5.0	7.1	2
TIBS3	0.0 $\pm$ 0.0	0.0	51.7 $\pm$ 36.5	77.5	35.4 $\pm$ 18.2	48.3	6.1 $\pm$ 8.6	12.1	2

Table A.4.43 Temporal variations in oil-drops of other size groups at TIB locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIBN3	99.6 $\pm$ 0.6	100.0	0.4 $\pm$ 0.6	0.8	0.0 $\pm$ 0.0	0.0	2
TIBN2	98.6 $\pm$ 2.1	100.0	1.5 $\pm$ 2.1	2.9	0.0 $\pm$ 0.0	0.0	2
TIBN1	95.4 $\pm$ 6.6	100.0	4.7 $\pm$ 6.6	9.4	0.0 $\pm$ 0.0	0.0	2
TIB0	99.2 $\pm$ 1.1	100.0	0.8 $\pm$ 1.1	1.5	0.0 $\pm$ 0.0	0.0	2
TIBS1	96.5 $\pm$ 4.9	100.0	3.5 $\pm$ 4.9	7.0	0.0 $\pm$ 0.0	0.0	2
TIBS2	95.2 $\pm$ 6.8	100.0	4.8 $\pm$ 6.7	9.5	0.0 $\pm$ 0.0	0.0	2
TIBS3	93.2 $\pm$ 9.7	100.0	6.9 $\pm$ 9.8	13.8	0.0 $\pm$ 0.0	0.0	2

Table A.4.44 Temporal variations in OD_{2.5} at TIG locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIGN3	0.0 $\pm$ 0.0	0.0	52.7 $\pm$ 28.8	73.0	41.8 $\pm$ 27.6	61.3	5.6 $\pm$ 1.1	6.4	2
TIGN2	0.0 $\pm$ 0.0	0.0	57.5 $\pm$ 8.3	63.4	39.4 $\pm$ 12.8	48.4	2.5 $\pm$ 3.5	4.9	2
TIGN1	0.5 $\pm$ 0.6	0.9	60.3 $\pm$ 12.6	69.2	36.6 $\pm$ 9.4	43.2	1.8 $\pm$ 1.3	2.7	2
TIG0	0.0 $\pm$ 0.0	0.0	73.4 $\pm$ 5.9	77.5	26.7 $\pm$ 5.9	30.8	0.0 $\pm$ 0.0	0.0	2
TIGS1	2.6 $\pm$ 0.6	3.1	61.3 $\pm$ 28.3	81.3	22.0 $\pm$ 9.0	28.3	4.4 $\pm$ 6.2	8.7	2
TIGS2	0.0 $\pm$ 0.0	0.0	52.3 $\pm$ 28.3	72.3	42.7 $\pm$ 26.3	61.3	4.7 $\pm$ 2.4	6.4	2
TIGS3	1.6 $\pm$ 2.2	3.1	74.2 $\pm$ 10.0	81.3	22.3 $\pm$ 9.4	28.9	1.0 $\pm$ 1.4	2.0	2

Table A.4.45 Temporal variations in oil-drops of other size groups at TIB locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
TIGN3	100.0 $\pm$ 0.0	100.0	0.0 $\pm$ 0.0	0.0	0.0 $\pm$ 0.0	0.0	2
TIGN2	99.3 $\pm$ 1.0	100.0	0.7 $\pm$ 1.0	1.4	0.0 $\pm$ 0.0	0.0	2
TIGN1	99.1 $\pm$ 1.3	100.0	0.9 $\pm$ 1.3	1.8	0.0 $\pm$ 0.0	0.0	2
TIG0	100.0 $\pm$ 0.0	100.0	0.0 $\pm$ 0.0	0.0	0.0 $\pm$ 0.0	0.0	2
TIGS1	90.3 $\pm$ 13.8	100.0	7.6 $\pm$ 10.7	15.2	2.2 $\pm$ 3.1	4.4	2
TIGS2	99.7 $\pm$ 0.4	100.0	0.3 $\pm$ 0.4	0.6	0.0 $\pm$ 0.0	0.0	2
TIGS3	99.0 $\pm$ 1.4	100.0	1.0 $\pm$ 1.4	2.0	0.0 $\pm$ 0.0	0.0	2

Table A.4.46 Temporal variations in OD_{2.5} at H and IN locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
H1	0.0 $\pm$ 0.0	0.0	31.6 $\pm$ 18.1	44.4	58.7 $\pm$ 32.0	81.3	2.8 $\pm$ 4.0	5.6	2
H 2	0.0 $\pm$ 0.0	0.0	65.3 $\pm$ 11.6	73.5	33.2 $\pm$ 13.7	42.9	0.0 $\pm$ 0.0	0.0	2
IN1	0.0 $\pm$ 0.0	0.0	46.1 $\pm$ 5.7	50.1	41.0 $\pm$ 23.9	57.9	6.1 $\pm$ 8.6	12.1	2
IN 2	0.0 $\pm$ 0.0	0.0	58.3 $\pm$ 6.0	62.5	38.8 $\pm$ 1.8	40.0	2.0 $\pm$ 2.8	4.0	2

Table A.4.47 Temporal variations in oil-drops of other size groups at H and IN locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
H1	93.1 $\pm$ 9.8	100.0	2.8 $\pm$ 4.0	5.6	4.2 $\pm$ 5.9	8.3	2
H 2	98.5 $\pm$ 2.1	100.0	1.5 $\pm$ 2.1	2.9	0.0 $\pm$ 0.0	0.0	2
IN1	93.2 $\pm$ 9.7	100.0	6.0 $\pm$ 8.5	12.0	0.9 $\pm$ 1.2	1.7	2
IN 2	99.0 $\pm$ 1.4	100.0	1.0 $\pm$ 1.4	2.0	0.0 $\pm$ 0.0	0.0	2

Table A.4.48 Temporal variations in OD_{2.5} at IE locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
IE1	6.6 $\pm$ 9.3	13.2	38.5 $\pm$ 12.9	47.6	35.6 $\pm$ 10.3	42.9	9.0 $\pm$ 5.9	13.2	2
IE 2	5.0 $\pm$ 7.1	10.0	37.4 $\pm$ 24.5	54.7	44.7 $\pm$ 21.6	60.0	13.0 $\pm$ 4.2	15.9	2

Table A.4.49 Temporal variations in oil-drops of other size groups at IE locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
IE1	89.7 $\pm$ 7.9	95.3	9.6 $\pm$ 6.8	14.4	0.9 $\pm$ 1.3	1.8	2
IE 2	100.0 $\pm$ 0.0	100.0	0.0 $\pm$ 0.0	0.0	0.0 $\pm$ 0.0	0.0	2

Table A.4.50 Temporal variations in OD_{2.5} at A locations

Location Code	OD _{0.44}		OD _{0.88}		OD _{1.77}		OD _{2.6}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
A0	3.2 $\pm$ 4.5	6.3	65.6 $\pm$ 4.3	68.6	24.9 $\pm$ 8.9	31.2	5.4 $\pm$ 7.6	10.8	2
A1	0.0 $\pm$ 0.0	0.0	52.2 $\pm$ 0.2	52.3	31.8 $\pm$ 19.4	45.5	7.1 $\pm$ 6.9	12.0	2
A2	0.0 $\pm$ 0.0	0.0	58.7 $\pm$ 1.8	60.0	33.9 $\pm$ 8.7	40.0	5.3 $\pm$ 7.5	10.6	2
A3	0.0 $\pm$ 0.0	0.0	36.1 $\pm$ 12.4	44.9	45.9 $\pm$ 18.6	59.0	11.9 $\pm$ 2.4	13.6	2
A4	23.5 $\pm$ 33.2	46.9	32.5 $\pm$ 19.4	46.2	39.4 $\pm$ 20.4	53.8	1.6 $\pm$ 2.2	3.1	2
A5	1.1 $\pm$ 1.5	2.1	63.4 $\pm$ 4.7	66.67	29.4 $\pm$ 15.0	40.0	4.2 $\pm$ 5.9	8.3	2

Table A.4.51 Temporal variations in oil-drops of other size groups at A locations

Location Code	OD _{2.5}		OD ₅		OD _{>5}		Sample Size (N)
	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	Mean $\pm$ SD	Max	
A0	99.0 $\pm$ 1.4	100.0	1.0 $\pm$ 1.4	2.0	0.0 $\pm$ 0.0	0.0	2
A1	91.0 $\pm$ 12.7	100.0	9.0 $\pm$ 12.7	18.0	0.0 $\pm$ 0.0	0.0	2
A2	93.0 $\pm$ 3.0	100.0	2.1 $\pm$ 3.0	4.2	0.0 $\pm$ 0.0	0.0	2
A3	93.9 $\pm$ 8.6	100.0	6.1 $\pm$ 8.6	12.2	0.0 $\pm$ 0.0	0.0	2
A4	96.9 $\pm$ 4.4	100.0	3.1 $\pm$ 4.4	6.2	0.0 $\pm$ 0.0	0.0	2
A5	98.0 $\pm$ 2.9	100.0	2.1 $\pm$ 3.0	3.0	0.0 $\pm$ 0.0	0.0	2

APPENDIX

V

**Table. A.5.1 Concentration of elements
at TIF locations (μgm^{-3})**

Element	TIFN3	TIFN2	TIFN1	TIF0	TIFS1	TIFS2	TIFS3
Pb	0.44	0.50	0.69	0.85	0.74	0.56	0.43
Ni	0.01	0.04	0.04	0.06	0.05	0.04	0.02
Cu	0.62	0.31	0.41	0.37	0.35	0.33	0.69
Cd	0.00	0.12	0.14	0.17	0.11	0.11	0.20
Cr	0.02	0.05	0.07	0.09	0.07	0.06	0.05
Fe	6.54	6.34	8.98	16.13	9.34	5.41	4.64
Zn	1.30	1.37	1.21	1.07	0.84	0.84	1.16
Mn	0.22	0.29	0.51	0.21	0.21	0.41	0.15
Co	0.19	0.17	0.18	0.17	0.19	0.15	0.19
K	1.17	1.74	2.05	2.94	1.93	1.82	1.51
Mg	1.54	1.77	1.90	2.87	2.23	2.04	1.24
Na	3.76	5.92	5.50	18.81	9.67	7.85	4.42

**Table. A.5.2 Concentration of elements
at TIB locations (μgm^{-3})**

Element	TIBN3	TIBN2	TIBN1	TIB0	TIBS1	TIBS2	TIBS3
Pb	0.68	0.71	0.86	1.16	0.88	0.85	0.82
Ni	0.02	0.04	0.05	0.05	0.04	0.02	0.02
Cu	0.65	0.53	0.53	0.49	0.32	0.50	0.50
Cd	0.00	0.00	0.00	0.01	0.08	0.01	0.01
Cr	0.01	0.01	0.03	0.05	0.04	0.03	0.01
Fe	5.61	6.84	4.19	4.75	6.44	7.43	3.41
Zn	0.92	1.19	1.23	0.96	1.13	1.20	1.10
Mn	0.64	0.28	0.66	0.22	0.24	0.26	0.50
Co	0.11	0.12	0.11	0.13	0.12	0.11	0.10
K	0.90	1.161	1.53	2.21	1.02	0.89	0.71
Mg	1.90	2.13	3.24	3.80	3.61	2.45	1.64
Na	3.80	3.62	6.46	10.73	7.86	3.50	2.48

Table. A.5.3 Concentration of elements at TIG locations ($\mu\text{g m}^{-3}$)							
Element	TIGN3	TIGN2	TIGN1	TIG0	TIGS1	TIGS2	TIBS3
Pb	0.68	0.76	0.83	1.08	0.96	0.88	0.76
Ni	0.00	0.01	0.05	0.10	0.06	0.06	0.02
Cu	0.49	0.50	0.48	0.54	0.33	0.56	0.63
Cd	0.07	0.06	0.00	0.04	0.06	0.03	0.07
Cr	0.02	0.03	0.04	0.04	0.03	0.03	0.02
Fe	1.27	7.86	10.15	10.78	12.70	11.87	9.12
Zn	0.88	1.07	1.03	1.00	1.30	0.89	0.65
Mn	0.00	0.02	0.10	0.00	1.27	0.07	0.00
Co	0.12	0.14	0.19	0.21	0.17	0.17	0.16
K	1.15	1.48	1.55	1.95	1.93	1.77	1.43
Mg	2.99	3.65	4.66	5.13	2.39	1.97	0.79
Na	5.27	6.98	9.71	24.60	10.04	8.77	8.23

Table. A.5.4 Concentration of elements at A locations ($\mu\text{g m}^{-3}$)						
Element	A0	A1	A2	A3	A4	A5
Pb	0.85	0.71	0.65	0.61	0.52	0.47
Ni	0.06	0.05	0.02	0.02	0.01	0.01
Cu	0.37	0.40	0.47	0.51	0.56	0.62
Cd	0.17	0.20	0.22	0.22	0.22	0.19
Cr	0.03	0.02	0.01	0.01	0.01	0.00
Fe	16.13	14.57	12.27	12.65	10.22	9.54
Zn	1.07	1.02	0.97	0.96	0.95	0.95
Mn	0.21	0.54	0.53	0.49	0.23	0.15
Co	0.18	0.16	0.13	0.11	0.09	0.07
K	1.94	1.69	1.05	1.72	1.01	1.12
Mg	2.87	3.15	5.56	5.15	3.32	3.23
Na	18.81	14.00	10.55	10.41	9.63	9.23

Table. A.5.5 Enrichment factors for elements					
Element	CB	MP	MU	HP	HU
Pb	424.63	704.08	847.39	883.86	643.73
Ni	1.42	2.48	2.53	2.39	2.01
Cu	81.06	25.34	29.35	34.27	19.15
Cd	2653.92	2091.08	2849.00	2468.58	1505.11
Cr	2.12	2.32	3.32	2.69	1.20
Zn	192.60	82.52	80.04	74.38	43.00
Mn	6.37	3.34	3.00	3.02	1.49
Co	8.49	29.74	34.19	30.52	19.26
K	0.30	0.71	0.48	0.91	0.35
Mg	0.42	1.74	1.42	1.68	0.87
Na	1.20	1.27	1.22	2.03	1.49

Table. A.5.6 Enrichment factors for elements at TIF locations							
Element	TIFN3	TIFN2	TIFN1	TIF0	TIFS1	TIFS2	TIFS3
Pb	258.76	303.32	295.53	202.68	304.72	398.12	356.43
Ni	1.02	4.21	2.97	0.02	3.57	4.92	2.87
Cu	86.18	44.45	41.51	20.85	34.07	55.45	135.19
Cd	0.00	4731.86	3897.55	2634.84	2944.32	5083.18	10775.86
Cr	1.53	3.94	3.90	2.79	3.74	5.54	5.39
Fe	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Zn	141.98	154.35	96.25	47.38	64.24	110.91	178.57
Mn	1.77	2.40	2.99	0.68	1.18	3.99	1.70
Co	58.10	53.63	40.09	21.08	40.68	55.45	81.90
K	0.34	0.54	0.44	0.35	0.40	0.65	0.63
Mg	0.56	0.67	0.51	0.43	0.57	0.90	0.64
Na	1.02	1.65	1.08	2.06	1.83	2.56	1.68

**Table. A.5.7 Enrichment factors for elements
at TIB locations**

Element	TIBN3	TIBN2	TIBN1	TIB0	TIBS1	TIBS2	TIBS3
Pb	466.20	399.23	789.43	939.27	525.56	440.00	924.88
Ni	2.38	3.90	7.96	7.02	4.14	1.79	3.91
Cu	105.33	70.44	114.99	93.78	45.17	61.18	133.30
Cd	0.00	0.00	0.00	526.32	3105.59	336.47	733.13
Cr	0.89	0.73	3.57	5.26	3.11	2.02	1.47
Fe	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Zn	117.14	124.27	209.68	144.36	125.33	115.36	230.41
Mn	6.00	2.15	8.29	2.43	1.96	1.84	7.71
Co	39.21	35.09	52.50	54.74	37.27	29.61	58.65
K	0.31	0.33	0.70	0.90	0.31	0.23	0.40
Mg	0.81	0.74	1.84	1.91	1.34	0.79	1.15
Na	1.20	0.94	2.72	3.99	2.16	0.83	1.28

**Table. A.5.8 Enrichment factors for elements
at TIG locations**

Element	TIGN3	TIGN2	TIGN1	TIG0	TIGS1	TIGS2	TIBS3
Pb	2059.36	371.89	314.51	385.33	290.73	285.14	320.51
Ni	0.00	0.84	3.28	6.18	3.15	3.37	1.46
Cu	350.75	57.83	42.99	45.54	23.62	42.89	62.80
Cd	13779.53	1908.40	0.00	927.64	1181.10	631.84	1918.86
Cr	7.87	1.91	1.97	1.85	1.18	1.26	1.10
Fe	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Zn	494.94	97.23	72.48	66.26	73.11	53.56	50.90
Mn	0.00	0.13	0.52	0.00	5.26	0.31	0.00
Co	188.98	35.62	37.44	38.96	26.77	28.64	35.09
K	1.74	0.36	0.29	0.35	0.29	0.29	0.30
Mg	5.63	1.11	1.10	1.14	0.45	0.40	0.20
Na	7.33	1.57	1.69	4.03	1.40	1.30	1.59

Table. A.5.9 Enrichment factors for elements			
Element	H	IN	I
Pb	386.74	407.14	339.59
Ni	4.30	3.00	1.74
Cu	50.32	50.16	27.35
Cd	4381.92	4504.50	981.03
Cr	0.92	0.56	1.96
Fe	1.00	1.00	1.00
Zn	81.70	105.37	61.66
Mn	3.25	2.13	1.65
Co	31.36	45.04	24.85
K	0.29	0.18	0.13
Mg	1.07	0.22	0.22
Na	2.86	2.54	1.58

Table. A.5.10 Enrichment factors for elements at A locations (μgm^{-3})						
Element	A0	A1	A2	A3	A4	A5
Pb	202.68	187.42	203.75	185.46	195.69	189.48
Ni	2.48	2.29	1.09	1.05	0.65	0.70
Cu	20.85	24.96	34.82	36.65	49.81	59.08
Cd	2634.84	3431.71	4482.48	4347.83	5381.60	4979.04
Cr	0.93	0.67	0.41	0.40	0.49	0.00
Fe	1.00	1.00	1.00	1.00	1.00	1.00
Zn	47.38	50.00	56.47	54.20	66.40	71.13
Mn	0.68	1.95	2.27	2.04	1.18	0.83
Co	22.32	21.96	21.19	17.39	17.61	14.68
K	0.23	0.22	0.17	0.26	0.19	0.23
Mg	0.43	0.52	1.08	0.97	0.78	0.81
Na	2.06	1.70	1.52	1.45	1.66	1.7

Table. A.5.11 Pearson correlation coefficients between elements at CB locations												
Element	Pb	Ni	Cu	Cd	Cr	Fe	Zn	Mn	Co	K	Mg	Na
Pb	1.00											
Ni	-0.82	1.00										
Cu	-0.61	0.95	1.00									
Cd	0.53	0.05	0.35	1.00								
Cr	-0.94	0.97	0.85	-0.20	1.00							
Fe	-0.94	0.57	0.29	-0.79	0.75	1.00						
Zn	-0.96	0.94	0.80	-0.28	1.00	0.81	1.00					
Mn	-0.46	-0.13	-0.42	-1.00*	0.13	0.75	0.21	1.00				
Co	-0.90	0.99	0.89	-0.11	1.00	0.69	0.99	0.04	1.00			
K	0.21	-0.73	-0.90	-0.72	-0.54	0.15	-0.46	0.77	-0.61	1.00		
Mg	-0.86	1.00*	0.93	-0.02	0.98	0.63	0.97	-0.05	1.00	-0.68	1.00	
Na	-0.92	0.94	0.79	-0.29	1.00	0.81	1.00	0.22	0.98	-0.45	0.96	1.00

* Significant (p<0.05)

Table. A.5.12 Pearson correlation coefficients between elements at MP locations												
Element	Pb	Ni	Cu	Cd	Cr	Fe	Zn	Mn	Co	K	Mg	Na
Pb	1.00											
Ni	-0.05	1.00										
Cu	0.48	-0.12	1.00									
Cd	-0.11	-0.06	0.34	1.00								
Cr	0.43	-0.15	0.52	0.23	1.00							
Fe	-0.03	-0.36	-0.17	-0.29	-0.30	1.00						
Zn	0.58*	-0.04	0.56*	-0.23	0.36	0.19	1.00					
Mn	-0.31	0.32	-0.01	0.11	-0.04	-0.03	-0.23	1.00				
Co	0.41	0.37	0.54	-0.26	0.42	-0.46	0.56*	-0.17	1.00			
K	0.49	0.42	0.04	-0.28	0.35	-0.36	0.40	0.19	0.38	1.00		
Mg	0.36	0.14	0.62*	-0.08	0.32	0.11	0.75*	0.18	0.42	0.39	1.00	
Na	0.24	0.51	0.41	-0.01	0.18	-0.61*	0.28	0.43	0.53	0.71*	0.52	1.00

* Significant (p<0.05)

Table. A.5.13 Pearson correlation coefficients between elements at MU locations

Element	Pb	Ni	Cu	Cd	Cr	Fe	Zn	Mn	Co	K	Mg	Na
Pb	1.00											
Ni	-0.21	1.00										
Cu	-0.15	-0.46	1.00									
Cd	0.11	0.36	-0.27	1.00								
Cr	0.02	-0.08	0.34	0.28	1.00							
Fe	-0.19	0.29	-0.15	-0.16	-0.37	1.00						
Zn	-0.79*	-0.00	0.30	-0.37	-0.04	0.32	1.00					
Mn	-0.25	-0.19	0.46	-0.34	0.30	-0.63*	0.27	1.00				
Co	-0.49	-0.18	-0.28	-0.27	-0.28	-0.05	0.55	0.18	1.00			
K	0.32	-0.48	0.15	-0.35	0.58	-0.11	-0.07	0.17	-0.05	1.00		
Mg	0.15	-0.60	0.03	-0.33	0.24	0.29	0.12	-0.26	0.17	-0.14	1.00	
Na	0.13	0.17	-0.22	-0.30	-0.19	-0.08	0.19	0.33	0.25	-0.57	0.16	1.00

• Significant ($p < 0.05$)

Table. A.5.14 Pearson correlation coefficients between elements at HP locations

Element	Pb	Ni	Cu	Cd	Cr	Fe	Zn	Mn	Co	K	Mg	Na
Pb	1.00											
Ni	-0.00	1.00										
Cu	0.11	-0.40	1.00									
Cd	0.34	-0.26	0.02	1.00								
Cr	0.16	-0.21	0.77*	-0.33	1.00							
Fe	-0.17	0.00	0.25	-0.18	0.22	1.00						
Zn	0.21	-0.53	0.16	-0.16	0.28	-0.60*	1.00					
Mn	0.61*	0.30	0.02	-0.08	0.23	0.10	-0.04	1.00				
Co	0.74*	-0.11	0.15	-0.10	0.37	0.08	0.23	0.60*	1.00			
K	0.77*	0.34	0.01	0.28	0.06	0.10	-0.26	0.62*	0.40	1.00		
Mg	0.86*	0.21	0.20	0.07	0.34	-0.17	0.24	0.68*	0.71*	0.57*	1.00	
Na	0.13	0.42	0.25	-0.26	0.10	-0.04	-0.02	0.18	0.16	0.07	0.47	1.00

• Significant ($p < 0.05$)

Table. A.5.15 Pearson correlation coefficients between elements at HU locations											
Element	Pb	Ni	Cu	Cd	Cr	Fe	Zn	Mn	Co	K	Na
Pb	1.00										
Ni	-0.04	1.00									
Cu	0.01	0.21	1.00								
Cd	0.49	-0.32	0.50	1.00							
Cr	-0.22	-0.01	0.29	-0.20	1.00						
Fe	-0.07	0.35	-0.41	-0.57	0.20	1.00					
Zn	0.32	0.26	0.52	0.18	-0.11	-0.41	1.00				
Mn	0.03	-0.06	0.21	0.00	0.09	0.43	-0.01	1.00			
Co	0.30	-0.24	-0.01	0.42	-0.76*	-0.52	0.05	-0.01	1.00		
K	-0.12	0.66*	-0.10	-0.48	0.04	0.57	0.00	0.38	-0.21	1.00	
Mg	0.19	0.04	-0.48	-0.37	-0.51	0.49	-0.02	0.25	0.18	0.29	1.00
Na	0.13	0.26	0.17	0.10	0.35	0.03	0.43	0.22	0.11	0.36	1.00

*Significant (p<0.05)

Table. A.5.16 Pearson correlation coefficients between elements and total vehicular density					
Elements	MP	MU	HP	HU	
Pb	-0.72*	-0.17	0.11	0.48	
Ni	0.24	0.35	0.17	0.43	
Cu	-0.34	0.03	0.10	0.48	
Cd	-0.09	-0.10	0.64*	0.52	
Cr	-0.27	0.05	-0.22	0.03	
Fe	0.02	-0.37	0.35	-0.40	
Zn	-0.18	-0.23	-0.70*	0.35	
Mn	0.42	0.36	-0.22	-0.33	
Co	-0.24	-0.24	-0.21	0.18	
K	0.02	-0.29	0.37	0.12	
Mg	0.13	-0.57	0.00	-0.44	
Na	0.11	0.06	0.05	0.12	

* Significant (p<0.05)

RESUME

Name : Sarvesh Chandra Katiyar

Date of Birth : 7th June 1960



Educational Qualifications:

Examination Passed	Board/University	Year	Result
High School	U. P. Board	1974	I st
I. Sc.	U. P. Board	1976	II nd
B.Sc.	Kanpur University	1978	I st
M. Sc.	Kanpur University	1980	I st
Ph.D.*	North Eastern Hill University	1998	***

Computer Proficiency:

- Microsoft Word, Microsoft Excel, Microsoft Power Point, Lotus SmartSuite, Costat and Statistica 4.5

Present Position:

- Scientist 'C' and Officer-in-Charge, Central Laboratory, Meghalaya Pollution Control Board, Shillong, Meghalaya
- Govt. Analyst, Govt. of India under Environment (Protection) Act, 1986 (April 90 till date), GOI, Notification No S.O. 375(E) dated 26.04.90 (Gazette No. 248 dated 10.05.90) and No S.O. 889(E) dated 31.08.96 (Gazette No. 738 dated 23.12.96)
- Govt. Analyst, Govt. of Meghalaya under Water (Prevention and Control of Pollution), Act, 1974 and Air (Prevention and Control of Pollution), Act. 1981 (Sept.90 till date), Notification No PHE: 235/90/7 dated 11.09.90

Positions Held:

- Scientist 'B' (July 88 to May 91), Meghalaya Pollution Control Board, Shillong
- Senior Research Fellow (Nov.85 to June 88), Dept of Chemical Engg. & Technology, Institute of Technology, Banaras Hindu University, Varanasi. Worked on research problem entitled "Anaerobic Treatment of Waste water and Solid Wastes with Biogas Production".

- Junior Research Fellow (Nov.83 to Oct.85), Dept of Chemical Engg. & Technology, Institute of Technology, Banaras Hindu University, Varanasi. Worked on research problem entitled " Anaerobic Treatment of Waste water and Solid Wastes with Biogas Production".
- Chemist (Jan.81 to Aug.83), Electrochem, Varanasi.

Memberships:

- Life Member of Indian Society of Analytical Scientists (ISAS)
- Life Member of Indian Association for Air Pollution Control (ISAC)

Other Information:

- Received "Certificate of Merit" for paper entitled "Nagar Ek Paryavarniya paripekshya" (published in the J. Institution of Engineers) by Institution of Engineers (India) during 1989-90.
- Established "Central Laboratory" of Meghalaya Pollution Control Board at Shillong (later recognized by Ministry of Environment & Forests, Govt of India, N. Delhi as 'A' Grade "Environmental Laboratory" Under Environment (Protection) Act, 1986 and as "State Water and Air Laboratory" by the Govt of Meghalaya under Water (Prevention and Control of Pollution), Act, 1974 and Air (Prevention and Control of Pollution), Act, 1981.

List of Research Papers:

1. **"Mass Loadings and Size Distributions of Vehicular Particulates at Breathing Level in Ambient Air of Shillong (India)"**, K. K. Dwivedi, S. C. Katiyar, D. T. Khathing, Accepted for Presentation in 8th International Conference on **"Urban Transport and Environment in the 21st Century"**, 13-15 March 2002, **Seville, Spain**.
2. **"Assessment of Breathing Level Ambient Air Quality of Shillong, India: Part-I Total Suspended Particulates"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, **Indian Journal of Environment Protection**, 000 (2002), 000.
3. **"Assessment of Breathing Level Ambient Air Quality of Shillong, India: Part-II Particle Size Distributions"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, **Indian Journal of Environment Protection**, 000 (2002), 000.
4. **"Characterization of Exhaust Emissions from Gasoline and Diesel Powered Vehicles"**, S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, **Pollution Research**, 000 (2002), 000.
5. **"Assessment of Total Suspended Particulates and Particle Size of Breathing Level Ambient Air of Shillong"** S. C. Katiyar, D. T. Khathing, K. K. Dwivedi, Presented in the Symposium on **"Pre concentration and Characterisation of Trace Constituents 'PACT'-An Essentiality"**, 26-27th May, 1999, Shillong, India.

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7. **"Water Quality Status of River Umshyrpi and its Tributaries"**, J. Sawian and S. C. Katiyar, Conference on Pollution, Man and Environment, Shillong, 15-16, June 1999.
8. **"Studies on the Ambient Air Quality of the Major Towns of Meghalaya"**, B. Nongbri and S. C. Katiyar, Conference on Pollution, Man and Environment, Shillong, 15-16th June 1999.
9. **"Environmental Impacts of Coal Mining in Jaintia Hills District of Meghalaya"**, S. C. Katiyar, Proceedings of "Conference on Science and Technology, 27-28th May, 1998, Shillong", 181-184.
10. **"Status of Air Pollution in Meghalaya"**, S. C. Katiyar, Seminar on Environmental Hygiene, Shillong, 5th June 1996.
11. **"Nagar Ek Paryavarniya Paripekshya"** S. C. Katiyar, K. K. Pandey and S. N. Upadhyay, Journal of Institution of Engineers Vol.7, Part 3(H), 50-61, Dec 1988.
12. **"Exploitation of Mineral Resources: The Environmental Perspective"** Indian Journal of Environmental Protection, Vol.8 No.2 Feb (r) 1988.
13. **"Environmental Effects of Cement Manufacture"** Seminar cum Workshop on "Advance in Ceramics" B.H.U., India, 10-11 Feb 1988.
14. **"Fertiliser from Domestic and Industrial Wastes"**, Seminar on Fertiliser Industry Process Problems and Perspectives, B.H.U., India, 21-23 Jan 1988.
15. **"Environmental Impact of Fertiliser production and Utilisation in India"** Seminar on Fertiliser Industry Process Problems and Perspectives, B.H.U., India, 21-23 Jan 1988.
16. **"Energy Exploration and Development of India: The Environmental Perspective"**, Conference on "Alternative Energy Sources" 8th Miami International Conference, Florida, U.S.A., 4-1 Dec, 1987.
17. **"Nagar Ek Paryavarinya Paripekshya"**, Conference on "Vijnan, Taknik Aur Paryavarana", organised by Vijnan Parishad, Allahabad 14 Dec 1987.
18. **"Energy Exploration and Development"**, The Environmental Perspective, MINMAG Vol. XVI, 42-51, Feb 1987.
19. **"Environmental Perspective of Urban Habitat"**, Conference on Environmental Management and Public Awareness, Varanasi, India, Dec 1986.