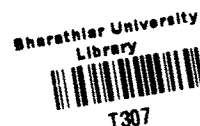
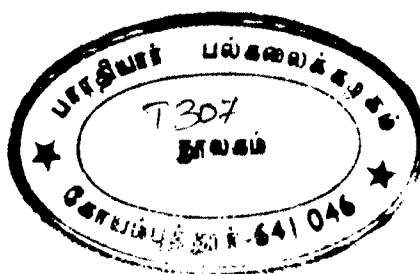


Air Quality of Coimbatore with Emphasis on Respirable Suspended Particulate Matter

Thesis submitted to the
Bharathiar University, Coimbatore

for the award of
DEGREE OF DOCTOR OF PHILOSOPHY
in
Environmental Sciences

by
R. Mohanraj

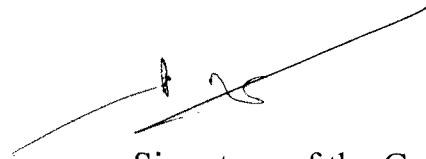


**Division of Environmental Impact Assessment
Salim Ali Centre for Ornithology and Natural History
Coimbatore - 641 108**

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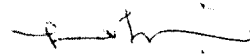
CERTIFICATE

This is to certify that the thesis, entitled “**Air quality of Coimbatore with emphasis on respirable suspended particulate matter**”, submitted to the Bharathiar University in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Environmental Sciences is a record of original research work done by **Mr. R. Mohanraj** during the period 1998 – 2002 of his study in the Division of Environmental Impact Assessment at Salim Ali Centre for Ornithology and Natural History, under my supervision and guidance and the thesis has not formed the basis for the award of any Degree/ Diploma/Associateship/Fellowship or other similar title to any candidate of any University.

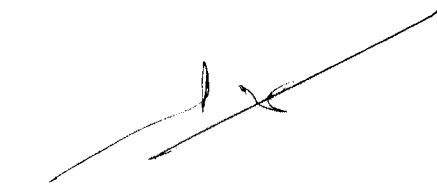


Signature of the Guide

Dr P. A. Azeez
Senior Professor, Consultant (EIA)
Salim Ali Centre
for Ornithology and Natural History
(Autonomous Centre, M.S.F. Govt. of India)
Anaikatty, Coimbatore - 641 108.



Director
Salim Ali Centre for Ornithology
and Natural History
Anaikatty P.O.
Coimbatore - 641 108.



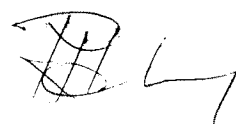
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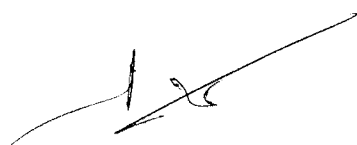
Dr P. A. Azeez
Senior Professor, Consultant (EIA)
Salim Ali Centre
for Ornithology and Natural History
(Autonomous Centre, M.S.F. Govt. of India)
Anaikatty, Coimbatore - 641 108.

DECLARATION

I, **R. Mohanraj** hereby declare that the thesis entitled “**Air quality of Coimbatore with emphasis on respirable suspended particulate matter**”, submitted to the Bharathiar University, in partial fulfillment of the requirements for the award of the Degree of Doctor of Philosophy in Environmental Sciences is a record of original and independent research work done by me during 1998 - 2002 under the supervision and guidance of **Dr. P. A. Azeez**, Senior Principal Scientist, Division of Environmental Impact Assessment, Salim Ali Centre for Ornithology and Natural History, Coimbatore and it has not formed the basis for the award of any Degree/Diploma/Associateship/Fellowship or other similar title to any candidate in any University.



Signature of the
Candidate



Countersigned

Head of the Department

DR. P. A. AZEEZ
Senior Principal Scientist
Division of Environmental Impact Assessment
Salim Ali Centre for Ornithology and Natural History
Coimbatore - 641 004
Tamil Nadu, India

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Summary

Particulate matter (PM), a complex mixture of organic and inorganic substances is an ubiquitous air pollutant, contributed by both natural and anthropogenic sources. Ever since the advent of industrial era, anthropogenic sources of PM have been increasing rapidly. Increasing amounts of such potentially harmful particles being emitted into the atmosphere on a global scale has resulted in damage to the health and environment. Recently it is also reported that soot particles have a heating effect to the atmosphere. Such heating effect can have wide implications on various systems of earth including climate.

PM in the atmosphere is categorized according to size because of different health impacts from particles of different diameters. PM with diameters of less than 50 μm are generally classified as Total Suspended Particulate Matter (TSPM). Particles that are greater than 50 μm in diameter do not remain in the atmosphere for appreciable lengths of time and present no health risk. Particulates with a diameter less than 10 μm defined as PM₁₀ or Respirable Suspended Particulate Matter (RSPM), enter the respiratory system and may become lodged in the alveoli resulting in wide range health effects including cancer and heart failures. PM₁₀ has the potential to travel long distances and cause cumulative effects. Other hazardous air pollutants may adhere to these particles, increasing their toxicity. These particles on wet and dry deposition are known to pollute local, regional and global land and water resources.

In India, increasing traffic, unplanned urban and industrial development, higher levels of energy consumption and high influx of population to urban areas are often cited as the reasons for the elevated particulate levels in the urban atmosphere by many studies.

Apparently between 1951 and 1991, the urban population has tripled, from 62.4 million to 217.6 million, and its proportion of the total population has increased from 17.3% to 25.7%. Nearly two-thirds of the urban population is concentrated in 317 class I cities (population of over 100 000), half of which lives in 23 metropolitan areas with populations exceeding 1 million. The number of urban agglomerations/cities with populations of over a million has increased from 5 in 1951 to 9 in 1971 and 23 in 1991. Vehicle population has grown from 0.3 million in 1951 to almost 40 million in 1997- 98, more than a hundred-fold increase, while during the period the total length of roads in the country has increased only by 7 fold.

Coimbatore city, the head quarters of the Coimbatore district is an important industrial city in India. The city and its urban environs with a population of 0.14 million occupies 17th position in terms of principal urban agglomeration of India. There are about 37,000 registered small-scale industries functioning in and around Coimbatore, employing more than one lakh workers. There are also more than 10,000 unregistered small-scale units (CODISSIA 2000). The number of medium and large-scale textile mills present in Coimbatore are 312 with 5 million spindles employing more than 65,604 workers. Coimbatore also meets almost 85% of the country's wet grinders demand, a major share in automobile parts and textile machinery. Industrial growth in the city had its serious overtones on the population and available public amenities. Since 1901 the population of the urban agglomerate has multiplied more than 17 times. In the wake of urbanization and industrialization, the number of automobiles is also rising at a similar pace. As on march 2000, the total number of vehicles registered in Coimbatore city has grown to 4,37,088. Coimbatore city generates more than 750 tonnes of garbage everyday. Garbage dumped in the city containing plastics and other toxic materials smolder invariably releasing huge amount of smoke. The rise in industries, population and vehicles exerts heavy pressure on

prevailing transportation infrastructure and other public amenities. The city is no exception to air pollution, an undesirable by-product of urbanization. However, till date no detailed documentation is available on air quality with emphasis on its chemical composition.

Current study in Coimbatore was undertaken to assess the air borne particulate matter and its chemical constituents. Six stations were selected in and around Coimbatore city for the study representing commercial and residential places in urban area, industrial area and sub-urban residential locations with following objectives.

- Study traffic pattern and vehicular emissions in Coimbatore
- Assess the atmospheric composition of SPM and its respirable fraction (PM 10).
- Determine significant constituents associated with RSPM such as heavy metals, cations and anions
- Assess RSPM bound polycyclic aromatic hydrocarbons (PAH)
- Understand the state of respiratory problems in Coimbatore

Study on emissions from the vehicles was performed using Netel Chromotograph Gas Analyser cum Smoke Meter. Ambient air quality was assessed a using respirable dust sampler with a cyclone attachment which fractionates the dust into respirable and non respirable fractions (Model. APM 451, fabricated by Envirotech, New Delhi, India). The respirable fraction was collected on a Whatman glass microfibre filter paper (GF/A - 203. X 25.4 cm), while SPM bigger than 10-microns (nonrespirable fraction - NRSPM) was collected in a separate sampling bottle. Sampling period at each station was 24 hours at monthly intervals. The RSPM and NRSPM were quantified separately for further analysis. The heavy metals (copper, chromium, cadmium, zinc and nickel) associated with RSPM were measured by atomic absorption spectrophotometer (Model: Perkin

Elmer 3300) after digesting a part of glass fibre filter with hydrofluoric, nitric and perchloric acid using microwave digestion system. Water-soluble cationic and anionic constituents of PM 10, particulate samples were extracted in ion free double distilled water for 6 hrs and centrifuged at 1500 rpm for 15 minutes. Supernatant was taken for the analysis of cations and anions following standard methods. For PAH analysis GF filter paper samples were extracted with cyclohexane/benzene, cleaned up using silica gel, concentrated the extract to 2-3ml and determined using GC- FID (Model Shimadzu 15 A). Data on status of respiratory health was collected in person through questionnaires and from hospital records.

In Coimbatore, on an average of 84.2 % of the total vehicles recruited annually were two-wheelers during 1994-2000. Of the 984 automobiles were examined for vehicular exhaust of which 71% was two-wheelers, 17% light duty cars and jeeps, and 12% heavy-duty vehicles such as bus, lorries and public carriers of passengers or goods. Irrespective of the vehicle type, about 20% of the vehicles examined in the study failed to comply with currently followed emission norms. In the case of scooters, light duty cars and commercial vehicles all those vehicles exceeding the emission limits were more than 5-year old vehicles. In the case of bikes, the increase in 4-stroke engines has resulted in less polluting vehicles. Bad quality of city roads, unhealthy practices of drivers, resuspension of road dust due to traffic movement are identified as the major problems that can add to vehicular pollution in Coimbatore.

In the present study the total SPM (RSPM + NRSPM)) ranged between 136.5 – 206.5 $\mu\text{g}/\text{m}^3$. RSPM concentration ranged between 30-149 $\mu\text{g}/\text{m}^3$ with an average of $71.3 \pm 22.26 \mu\text{g}/\text{m}^3$, while NRSPM ranged between 24.4 – 460 $\mu\text{g}/\text{m}^3$ averaging $110.8 \pm 69.15 \mu\text{g}/\text{m}^3$. Urban air samples and samples collected near the highway exceeded permissible

limit ($60 \mu\text{g}/\text{m}^3$) set by Central Pollution Control Board as annual average. Rise in SPM levels compared to the earlier studies, may be probably attributed to the rapid increase in vehicular population and traffic congestion. Wind speed was negatively correlated with RSPM, while it had a positive correlation with NRSPM. This indicates that higher wind speed has high dilution effect on fine particles especially (RSPM), while a strong wind is likely to resuspend the dust particles present in the ground contributing to higher NRSPM concentrations. Temperature also had a negative correlation with RSPM values.

Heavy metal concentrations in RSPM were in the range Below Detectable Limit (BDL) – $2147 \text{ ng}/\text{m}^3$ with abundance varying in the order $\text{Zn} > \text{Cu} > \text{Pb} > \text{Ni} > \text{Cr} > \text{Cd}$. Significant positive correlation among metals excepting lead and copper suggests that mostly they originate from a common source. Samples of urban and industrial areas showed higher concentrations than residential (urban) and suburban areas. In TSPM, an average of 81% of lead, 89% of zinc, 86% of cadmium and 79% of copper were found in RSPM fraction. NRSPM bound heavy metals were in the following range; $\text{Cu} = 9\text{-}550.6 \text{ ng}/\text{m}^3$, $\text{Pb} = 2.2\text{-}254.8 \text{ ng}/\text{m}^3$, $\text{Zn} = 5.7\text{-}760$, $\text{Cd} = \text{BDL} - 2.8 \text{ ng}/\text{m}^3$. No significant correlation was observed among the heavy metals and meteorological parameters.

Among the water-soluble inorganic constituents estimated, sulphate was observed as dominant compound. Observed range of these ions were; sulphate = $0.35 - 11.4 \mu\text{g}/\text{m}^3$, chloride = $0.5 - 9.8 \mu\text{g}/\text{m}^3$, sodium = $0.23 - 6.9 \mu\text{g}/\text{m}^3$, potassium = below detectable limit (BDL) – $2.8 - 9 \mu\text{g}/\text{m}^3$, phosphate = $20.5 - 1193 \text{ ng}/\text{m}^3$ and nitrate = $10.22 - 425.25 \text{ ng}/\text{m}^3$. Except chloride, all other anions and cations had positive relation with RSPM suggesting that majority of them have similar source. Higher chloride values obtained in

the industrial area (Station D) may be due to the presence of foundries in the industrial estate using large quantity of sea sand for the casting process.

A total of 13 PAH compounds were analyzed in RSPM samples collected on glass fibre filters from six sampling stations. Total PAHs (13 compounds) in samples ranged between 20 – 172 ng/m³ with an average 90.37 ± 57.4 ng/m³. Samples from urban and industrial area are had higher PAH concentration than the suburban/rural sample, indicating vehicular traffic and industries as major anthropogenic sources for PAH. In the current study, naphthalene was observed high in samples (15.9 – 50.12 ng/m³).

Among 635 respondents for questionnaire survey, 53% suffer from the respiratory disorders and other associated ailments. Among the 443 male respondents 236 individuals are affected by the respiratory problems. Among 192 female respondents 103 suffer respiratory and related disorders. Among males and females who suffer from respiratory problems, about 60 and 62% live in urban/city environment, 33 and 30% in sub-urban areas respectively. Among the respondents, who do not have respiratory problems, rural residents seem to be higher (15%), indicating the urban environment as one of the probable reason for respiratory ailments. Majority of the people suffering from respiratory ailments experience its intensity during winter or winter and rainy season. During winter months, the atmospheric RSPM are also higher suggesting that it may have role in respiratory disorders or aggravation of respiratory problems.

Issue of air quality deterioration and its health impacts have become wide concern among the urban Indians. The need for air pollution abatement is being recognised as an inevitable issue. Although automobile and oil industry had initiated measures on cleaner fuel and emission reduction, public and civic authorities role is significant in curbing

vehicular pollution. In Coimbatore to improve the air quality, constructive city planning city has to be carried out before allowing additional mushrooming of the city. Separation of industry and habitation, although earlier it was envisaged as effective, has practically collapsed after a period. Traffic congestion is currently common, haphazard community emergence and congestion is currently common in the city. Construction of ring roads, encouraging proper parking space, proper road disciplines, training to drivers of heavy commercial vehicles ^{may} _^ relent in emission levels to certain extent.

Developing countries have been copying air pollution control strategies from developed countries instead of building their own measures based on their local political and economic conditions. In India standards for air quality probably needs further revision after a thorough analysis of epidemiological state of the country in various representative zones.

Many studies have found an inverted U shaped relationship (Environmental Kuznets Curve – EKC) between environmental quality (especially air quality) deterioration and economic growth. The explanation for such relationship was (i) use of environment as a major source of inputs and a pool for waste assimilation increases at the initial stage of economic growth, but as country grows richer, the structural changes that take place would result in environmental protection, (ii) the status of environment quality changes from luxury to necessary good, technological developments and rise in public spending on environmental R&D are considered as important factor in improvement of the environmental quality. Similar is situation in India where economic growth and percapita national income has been increasing since economic liberalization since 1991. However, whether India would follow environmental kuznets curve remains to be investigated.

CHAPTER 1

General Introduction

1.1 Introduction

Atmospheric particles and gases play vital role in chemical and physical processes taking place in the atmosphere, subsistence of living organisms and the whole biosphere. These constituents restrict harmful UV radiation and maintain solar radiation reaching the earth. Formations of water droplets and ice crystals in atmosphere are highly influenced by atmospheric particles. Nutrient and Biogeochemical cycles are incomplete without active participation of aerosols. Airborne gases and particles were never envisaged as a threat to the ecological balance until the dramatic changes in their concentrations with the advent of industrial era. Anthropogenic emissions from various industrial, domestic and automobile sources have increased manifold and eventually have led to many global problems. Nearly 3000 different anthropogenic air pollutants have been identified, of which most are organic (including organometals). Combustion sources, especially vehicles emit about 500 different compounds. However, only for about 200 such compounds, the impact on environment and human beings have been investigated (Fenger 1999) to a notable extent.

The multi faceted global impacts of air pollution such as global warming and ozone depletion has received wide attention of scientific community as well as decision makers and international policy makers. A number of international panels, committees, conference of parties and summits were organized to discuss the issues and reach at international understandings, treaties or protocols. According to third assessment report of Intergovernmental Panel on Climate Change (IPCC 2001), the global average surface temperature has increased over 20th century by about 0.6^oC. It was observed that globally 1990's was very likely the warmest decade and the year 1998 was warmest in the

instrumental record so far. Anthropogenic emissions are suspected to be the major cause of these climatic changes. The report reveals that green house gases that cause positive radiative forcing on the earth surface, such as CO₂ and N₂O has increased by 31% and 17% respectively since 1750. Black carbon aerosols emitted from burning of fossil fuel also contribute to the positive radiative forcing (+0.2 Watts/m²). Another recent experimental study also witnessed that aerosols, especially soot particles have a heating effect to the atmosphere (Mitra 2001) that can have wide implications on various systems of earth. It alters the rate of photosynthesis. It changes the pattern of rainfall. When more droplets form within a given cloud, the available water is spread more sparsely, making each droplet smaller. This prevents the droplets to grow large enough to form rain (Schrope 2000, Satheesh 2002). It is evident from the worldwide studies that tiny particles and certain gases in air eminently contribute to the constant increase in acute and chronic respiratory problems, cardiovascular hospitalizations, pulmonary dysfunction and cancer. In developing countries like India air pollution has become a deep-rooted problem with rising haphazard urbanization occurring without much planning in infrastructure and fund allocation.

1.2 Particulate air pollutants

Air pollutants are aerosols, gases and vapors, if present in the atmosphere in such concentrations capable of inducing climatic changes, affecting human health and causing genetic and physiological alterations in terrestrial organisms. Aerosols are the liquid or solid particles dispersed in air. Based on the particle size, chemical state and formation process, aerosols are distinguished into dust, fume, smoke, mist, fog, smog, haze and condensation nuclei (Lippmann 1992). Suspended Particulate Matter (SPM) refers the mixture of solid and liquid particles in air. In broader sense the term applies to the matter

in atmosphere divided into particles having a lower size limit of the order of $10^{-3}\mu\text{m}$ and an upper limit of $100\mu\text{m}$ (Markatos 1993). SPM that has an aerodynamic diameter of below 10 microns are called as PM 10 or Respirable Suspended Particulate Matter (RSPM). The ultrafine particles of size range less than $0.1\mu\text{m}$, are formed by nucleation. Fine particulate matter of aerodynamic diameter $0.7-1\mu\text{m}$ is formed by accumulation or coagulation of ultra fine particles (Chow 1995). The major components of fine particles often are of sulphates, carbonaceous materials, nitrates, trace elements and water. The coarse particles are primarily composed of aluminosilicates and other oxides of crustal elements in soil (Bahadori et al 1999, Gamble 1998).

The atmospheric residence time of fine particles varies from days to months while that of coarse particles is only few hours as they are readily removed by rainfall and sedimentation (Markatos 1993, Rao 1991). The removal of atmospheric particulates by wet and dry deposition mechanism represents major source of land and water pollution (Cabon 1999).

PM 10 fraction, and more the PM 2.5 (particulate matter of aerodynamic diameter below 2.5 microns), is in recent focus of the world community as it penetrates deep into the respiratory system of human beings and causes many health disorders. Several epidemiological studies have documented worldwide the association of air borne particulate matter and adverse health effects including cancer, lung dysfunction, cardiovascular disorders, hospital admissions, morbidity and mortality (Wichmann et al 2000a, Pope III et al 2002, Lee and Schwartz 1999, Dockery et al 1992, Dockery et al 1993, Spix et al 1993).

1.3 Air pollution – a historical perspective

The history of air pollution from human activity is as old as man learned to start fire (Turk 1989). Its impact on human health rolls back to the period of pre-industrial antiquity (Brimblecombe 1999). Mummified lung tissues showing anthracosis, roughening of the maxillary sinus bone, and sinusitis in past populations are evidence of people living in smoky places. In the past, odor, such as stench from rotten organic matter, cooking foods, beef boilers and soap makers, was considered as major concern. Air pollution indeed became significantly noticeable only when a radical shift occurred from wood as a fuel to coal. Abundance and low cost fostered the transition to coal from wood for production activities. Later in 17th century coal was adopted as domestic fuel in London and other parts of Europe. Subsequently, impacts of coal burning like deterioration of health, vegetation, animals, paintings and furnishings also became apparent. The dramatic increase in smoke pollution also led to changes in clothing, where white clothings were avoided and even umbrella came as black to ward off soot-laden rain. Increasing industrialization and use of coal in industries further aggravated the air quality and health problems (Brimblecombe 1999).

The 19th and 20th centuries witnessed several dreadful disasters due to air pollution that resulted in high human mortality and morbidity, and pathological changes in cattle (Lippmann 1998, Pearce 2002). During 19th century various fog episodes caused excess of bronchitis deaths. For example during London fog disasters in 1873, 1880, 1882, 1891 and 1892, associated human deaths due to bronchitis during and succeeding weeks of the fog accounted to 788, 1817, 555, 1388 and 309 respectively. The fog on December 1952 in London is a catastrophe that claimed over 4000 lives from the exposure to air pollutants. The December 1962 fog episode (London) also recorded about 3200 deaths. Many such notable air pollution episodes that resulted in human mortality and injuries,

damage to vegetation and cattle are reported worldwide (Faith and Atkission 1972). One of the biggest air pollution tragedies although different from the previous discussed episodes as it was an accident, occurred at Bhopal, India on 2-3 December 1984 at Union Carbide Factory (UCF). Nearly 40 tones of highly toxic methyl isocyanate were accidentally discharged into the atmosphere, killing about 2500 men, women and children and 2100 animals (Misra and Tiwari 1992). More than 1 lakh people continue to suffer from physical and psychosomatic disorders.

Air pollution cause immense damage to historical and cultural monuments across the world. Particulate with a high primary acidity load essentially containing mineral fractions, have clearly seen devastating basic building materials such as marble and calcernite (Primerano et al 2000). Camuffo (1991) in a study on microclimatic effects to the Leonardo's "Last Supper", attempted to evaluate the direct and indirect effects of the deposition rate of air pollutants, hygrometic factors and present day exposition to crowds. Leonardo's "Last Supper" was painted in the refectory of St.Maria Grazie in Milan in 1498. Deterioration of "Last Supper" started as early as 1517 and initial restoration was done during 1770, in which the painting was drenched in oil in order to make more vivid the colors that were covered with efflorescences and mould, and consolidate the thin layer of color coating. Over the centuries "Last supper" is subject to many complex deterioration and also restorations.

India is a land of cultural heritage having a large number of highly invaluable monuments of ancient origin. Some of these monuments even date back to BC period. Many monuments in the urban areas have already lost their splendor and architecture, due to air pollution. A classic example is Tajmahal of Agra, one among the Seven Wonders of the World that is subject to severe air pollution. Tajmahal, the monument made of marble, is

found to lose its luster mainly due to emissions from 70,000 generators operating in Agra because of power shortage, increasing number of three wheelers running on diesel, impact of emissions from Mathura petroleum refinery, 292 coal based industrial units (Down to earth 1997b), wood combustion and brick kilns (Kulsreshtha et al 1995). Several such air pollution damages to historical buildings are noticed through out the country.

1.4 Air pollution – ecological implications

Air pollutants deposited in the forest ecosystems may react with any component of the ecosystem, either as nutrients facilitating growth or as toxins causing cell injury (Ulrich 1984). The most obvious ecological effect of pollution stress is alteration of species composition of biological communities through elimination of sensitive species or individuals (Barret and Bush 1991). Terrestrial ecosystems are exposed to multiple air pollutants from diverse industrial sources of widespread geographical origins. According to McLaughlin and Norby (1991), damages to plants due to air pollutants are widely seen, although their toxicity to a plant varies based on the amount of pollutant actually entering the plant, rate of entry, plant phenology and environmental conditions.

In W. Germany during 1970's foliar disease attributable to air pollution included diverse effects including yellowing of leaves, premature loss of needles from conifers resulting in thinning of canopy, changes in growth pattern of shoots and hormonal imbalances. Regional scale decline in white pine (*Pinus strobus*) in US was ultimately found associated with chronic stress from air pollution. In Germany during 1982, 8% of the trees were found unhealthy, a year later 34% of trees were affected and by 1984 over half of the trees were sickly and dying (Turk 1989), mainly due to fall in air quality. Acidification of soil, an indirect effect of air pollution is also expected to cause damage to

vegetation and forest cover. Significant damages in leaf structures of avenue trees such as *Azadiracta indica* and *Polyalthia longifolia* are noticed due to air pollution (Kulshreshtha 2000). In plants collected from heavy traffic areas the epicuticular wax was severely eroded and its morphology altered. Significant changes in cuticular and epidermal structures were also observed. A recent investigation by Kaupp et al (2000) found that particle bound hazardous compounds such as polychlorinated dibenzo-p-dioxins, dibenzofurans and polyaromatic hydrocarbons deposited on leaves of maize migrated through epicuticular waxes causing plant accumulation of these micro-organic contaminants.

1.5 Objective of the current study

Coimbatore is an important industrial town of South India. A survey of the literature shows that there is no detailed study conducted on air pollutants with emphasis to chemical composition of suspended particulate matter in Coimbatore. Moreover the RSPM in atmosphere is largely unattended in erstwhile studies on air pollution in the city. Large number of industries and automobiles in the city demands a better understanding of the chemical nature of the particulates and the state of respiratory problems that are supposed to be closely associated with particulate pollution. In this context, the study was undertaken with the following objectives;

- To study traffic pattern and vehicular emissions in Coimbatore
- Assess the atmospheric composition of SPM and its respirable fraction (RSPM).
- Determine significant constituents associated with RSPM such as heavy metals, cations and anions
- Assess RSPM bound polycyclic aromatic hydrocarbons (PAH)
- Understand the state of respiratory problems in Coimbatore

CHAPTER - 2

Study Area – Coimbatore

2.1 Introduction

Coimbatore city, the head quarters of the Coimbatore district is an important industrial city in the state of Tamilnadu, India. The district has a population of 3.5 million, of which about 0.184 million are urban and the rest rural (Population Census of India 1991). The total urban area of the district is 932 km². The Coimbatore city and its urban environs with a population of 0.14 million occupies 17th position in terms of principal urban agglomeration of India (http://www.citypopulation.de/Indien_j.html). The Coimbatore city and its environs have been rapidly burgeoning since 1932, after the electric power from the Pykara hydroelectric power station became available to Coimbatore.

Successful cotton crops provided primary drive for flourishing textile industry in Coimbatore. Cotton ginning, spinning and textiles mills are the backbone of the industrial growth of Coimbatore and its suburbs. The boom in textile industry flagged way for emergence of a number of auxiliary and allied industries, subsequently converting the city into a major industrial hub of south India. Geographical position of the city, on the immediate east of the pass, the Palghat gap (Figure 2.1), across the Western Ghats, providing direct access for traders from west coast (Harris et al 1990) further boosted its commercial prosperity. The rapid growth in industry and commerce influenced inception of many educational institutions, especially engineering and technical training institutes in and around Coimbatore. Developments in commercial, industrial and educational sector promoted immigration from the nearby districts and neighboring states. However, a pace in the development of public amenities and other infrastructure corresponding to the mushrooming population and haphazard development

of industries is wanting. A rapidly progressive growth of the economy has created an almost chaotic situation leading to decline in cleaner environment and public health.

2.2 Location, soil, geology and climate

Coimbatore city, situated between 10° 57' and 11° 02' North and 76° 56' and 77° 02' East have an average elevation of 442 meters above mean sea level. The extent of city is 105.6 km². Of this developed area constitutes to 52% while the rest are agricultural, unused and wastelands. Towards the west of the city lies the Western Ghats (Figure 2.1) rich in flora and fauna. Several streams originating in Vellingiri and Siruvani hills of the Western Ghats joins together to form river Noyyal that flows through the Coimbatore city. About 28 wetlands in the urban Coimbatore are fed by the river Noyyal. A large extent of agricultural land is also irrigated by the Noyyal river system in Coimbatore.

The most common rocks are the gneiss, granites and quartz. Major types of soil are red soil, sand and gravel with moderate areas of red and black loams (Chandrabose and Nair 1988). Limestone is found abundant in the hills near Madukkarai (approximately 12 km south of city). A large-scale cement industry, Associated Cement Companies Ltd, present at Madukkarai is based on this limestone reserves.

The state of Tamilnadu is characterized by four main seasons (Climate of Tamilnadu 1999). The cooler period from January to February is followed by the premonsoon season (or hot weather period) from March to May. The period from June to September have the southwest monsoon and the period October to December, forms the post-monsoon period (or retreating monsoon). The period from October to December, receiving northeast monsoon, is the main rain-bearing season in Tamilnadu and southeast peninsula.

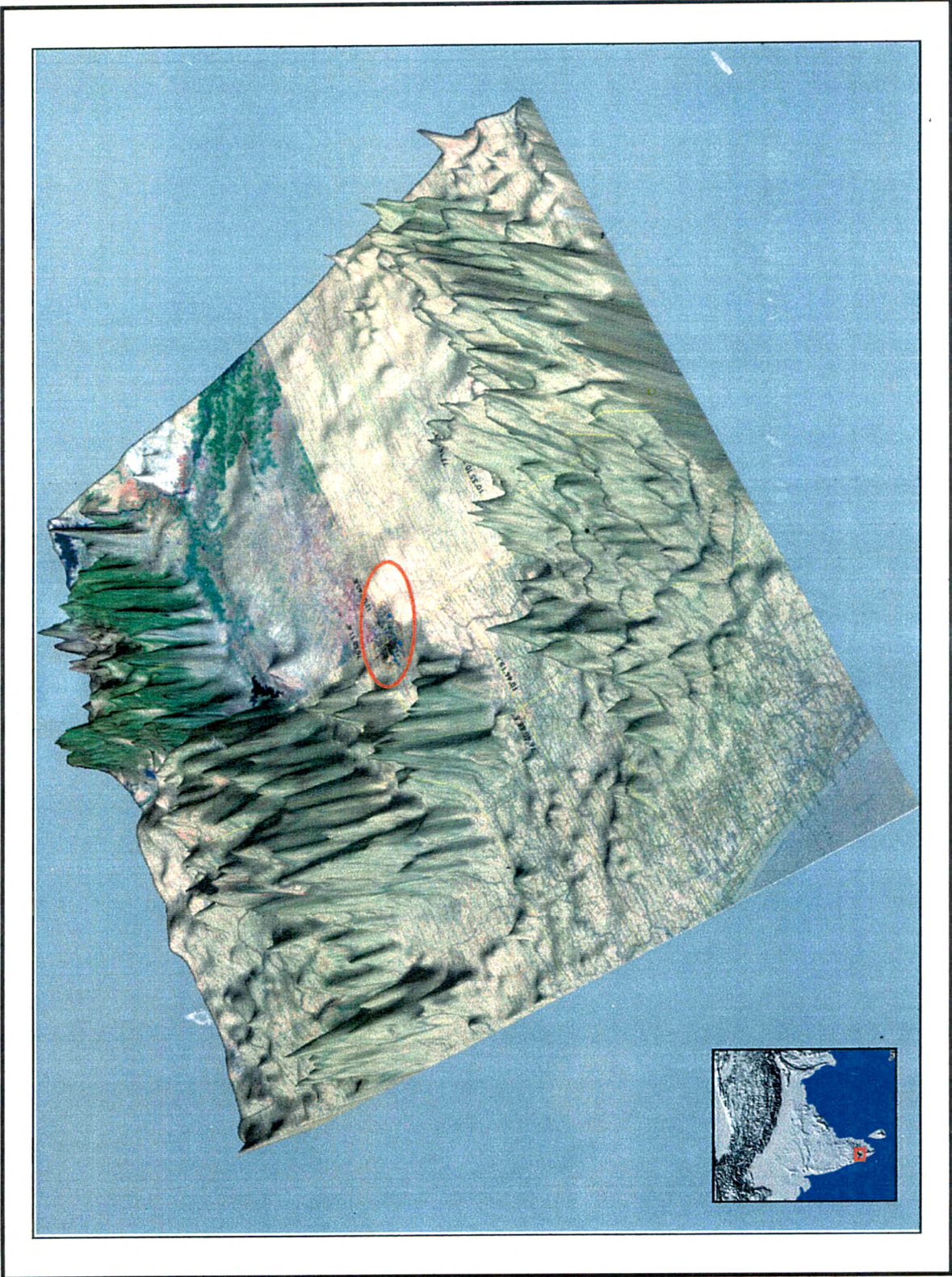


Figure 2.1 Map showing geographical position of Coimbatore city

During October to December a series of cyclonic systems crossing east coast influence the weather of the state. The period from January to February is comparatively pleasant with lower temperature.

In Coimbatore district summer is comparatively cooler than the neighboring districts. The summer from mid February to May is followed by southwest monsoon from June to September. October and December constitute the post monsoon season or the northeast monsoon season. From December to the first half of February is the coolest season. April and May are generally hottest months with mean daily average maximum temperature about 35°C and mean daily minimum temperature about 22°C. December and January are the coolest with mean daily average maximum temperature about 29°C and mean daily minimum temperature is about 19°C. During October to April, the winds are light while May onwards the wind force strengthens till September (Table 2.1).

Table 2.1 Average wind speed and direction recorded during past 50 years

Wind	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Speed (km/hr)	10	11	12	14	20	29	28	28	23	14	9	10
Direction	NE	NE	NE	NE	SW	SW	SW	SW	SW	SW	NE	NE
Source: Climate of Tamilnadu (1999)												

Mornings in general are humid than afternoons, with the humidity exceeding on an average 78%. During the period June to November, in the afternoons the humidity exceed 66% on an average. Morning mist occurs during the northeast monsoon on some days. Scanty and uncertain rainfall and high winds prevail in the region opposite the Palghat gap during May to July. The normal annual rainfall in the district is 1129.6 mm with an average 55 rainy days in a year. The micrometeorology of Coimbatore during the study period is discussed in Chapter 3.

2.3 Industrial Growth

Industrial growth in Coimbatore started with the establishment of two large textile mills in 1911. The period between 1951 and 1961 witnessed emergence of over 20 large mills in the city and its immediate vicinity. Currently there are 312 medium and large-scale textile mills with 5 million spindles employing more than 65,604 workers (SIMA 2000). The power and irrigation projects promoted agricultural development in regions of the district with scarce resources for irrigation. This brought in its wake, the evolution of the pump industry at par with the textile industry. In early thirties Coimbatore produced the first pump in the country. The pump industry provided the necessary base for light engineering entrepreneurs to venture into the manufacture of indigenous textile machinery accessories and spares. Currently, there are about 37,000 registered small-scale industries functioning in and around Coimbatore, employing more than a lakh of workers. There are also more than 10,000 unregistered small-scale units (CODISSIA 2000). In Coimbatore city itself there are about 12168 industries (Table 2.2). The industries of Coimbatore now produce a variety of engineering products ranging from small plastic items to large textile machinery. The major industrial activities of small-scale units are foundry castings, machine tools, cutting tools, electric motors and pumps, textile machinery, spares and components, plastics, washing machines, electrical appliances etc. There are around 3390 basic metal and metal product industries of which about 650 are foundry castings. Cotton textiles, textile processing and garment making units of urban Coimbatore numbers to more than 3050. Presently about 60% of India's requirements of pump-sets are met from Coimbatore. Within the country, almost 85% of the wet grinders, a major share of automobile parts and textile machinery is also produced here (The Hindu 1998). The industrial sector of the district is growing at a fast pace and occupies about 7.84% of land in urban Coimbatore. In the decade 1980-90 increase in

the number of workers in spinning and composite mills was approximately 48% (Signpost industrial directory of Coimbatore 1984), while it was only 17% for the whole state of Tamil Nadu.

Table 2.2 Details of small-scale industry within Coimbatore city limit

Industry Type	Numbers
Food products, Beverages and Tobacco products	329
Cotton Textiles, Hosiery & Garments, Synthetic Fibre	1835
Paper, Wood, Leather, Rubber and Plastic products	2062
Foundries, Metals and Alloy industries	2158
Electrical Machines, Machinery spares and Allied Industries	4338
Other Industries	1446

2.4 Population

India's population crossed one billion on May 11, 2000, which is 16% of world's population living in 2.4% of global land area (The Hindu 2001a). Coimbatore is the third most populated city of the state of Tamilnadu and 17th most populated city in India. Since 1901 the population of the Coimbatore city has multiplied more than 17 times (Table 2.3). During 1911 the Coimbatore city (Then municipality) had 47007 persons. The electric power supply made available for the industrial, commercial and domestic purposes encouraged industrial growth subsequently encouraging growth of population. A notable hike in population was observed during 1981, due to inclusion of two more regions to the city limits. According to Coimbatore Corporation authorities and Statistical Department of Government of Tamilnadu the population in 2001 is around 0.97 million. The population density in residential area in the old part of city is high ranging from 300 to 625 persons per hectare (B.B Street, N.H. Road, Sukrawarpet), while the density of population in other parts of the city such as P.N.Palayam, R.S.Puram and Tatabad is around 300. The average density of population in the whole Coimbatore city according to 1991 census was 185 persons per hectare.

Table 2.3 Population growth of Coimbatore City

Year	Population
1911	47007
1921	65788
1931	95198
1941	130348
1951	197755
1961	286305
1971	356368
1981	700923*
1991	806312
2001	970000**

*Due to incorporation of two more areas.
** Estimated population, Source (CLPA 1994).

2.5 Sampling locations for the current study

For the current air quality study, six stations were selected in and around the Coimbatore city (Figure 2.2). The locations were chosen to represent commercial and residential places in urban, industrial and sub-urban locations. The state of each sampling station is briefly described below.

2.5.1 Station A: State Bank of India (SBI) Road (Urban and Commercial mixed)

Coimbatore railway station, several government offices including district court, collector's office and police commissioner's offices are situated near the sampling station located on the SBI road. Commercial centers mainly dealing with electrical, electronics and mechanical goods and accessories are situated towards northwest and west of this location. Prominent sources of air pollution near this station are i) sizable volume of traffic flow always noticeable in and around the sampling point due to the nearby railway station and government establishments ii) At about 1km distance lies Valan lake, where garbage from near by places are dumped and frequently burned leading to serious release

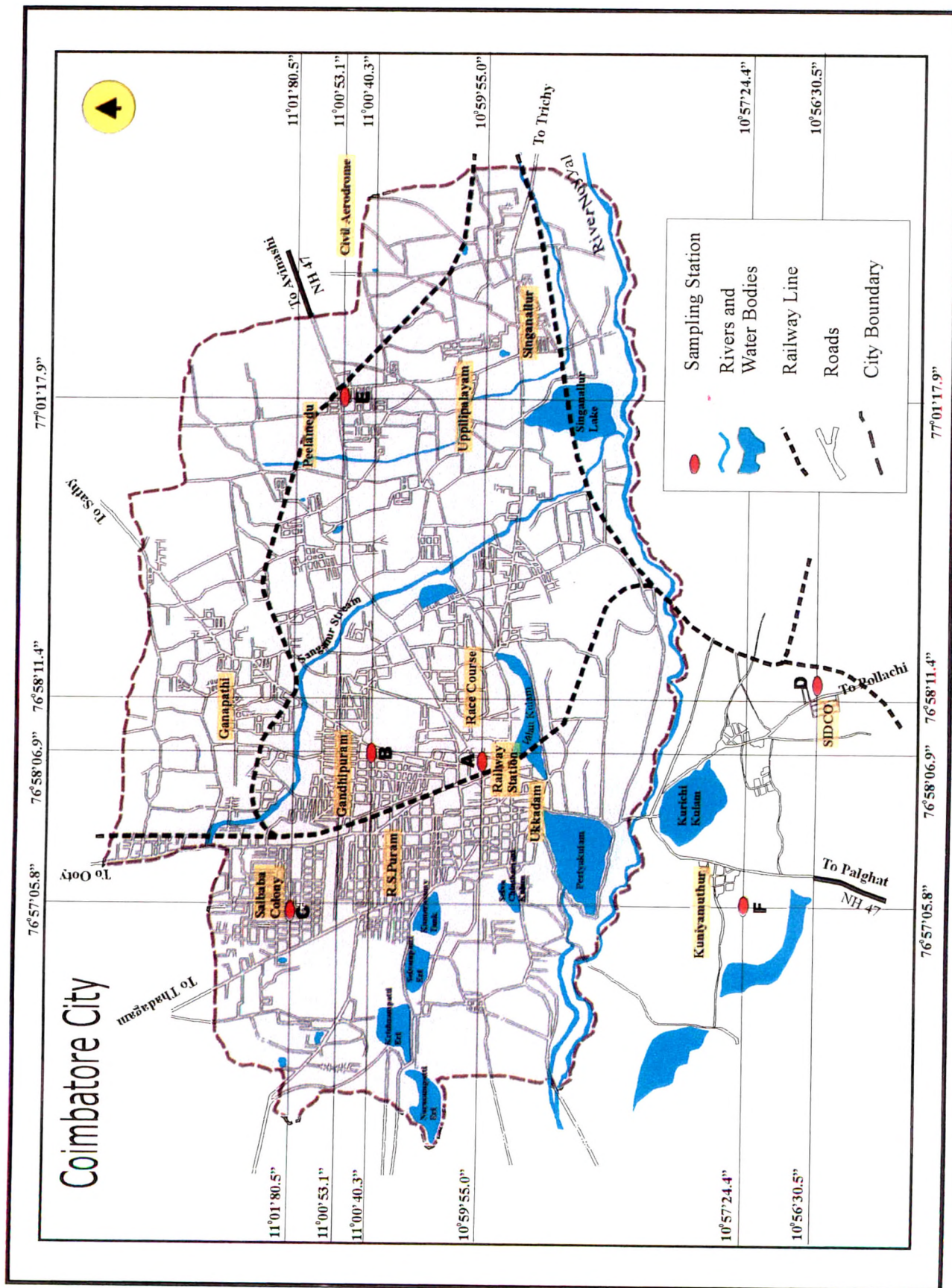


Figure 2.2 Map showing sampling stations in Coimbatore

of smoke. Few large-scale textile mills present in the close vicinity may also contribute to the cotton fibers in the atmosphere.

2.5.2 Station B: Gandhipuram (Urban and Commercial mixed)

Sampling station B is located about 50 meters from Dr. Nanjappa Road at Gandhipuram. Gandhipuram is considered as hub of Coimbatore city as it acts as terminus for many city, inter city and inter state buses. All the three bus stands lie in proximity at a distance of 100-200m from each other. The sampling station B lies almost at 500m from the bus terminuses. Several roads of commercial importance and to other towns radiate from Gandhipuram. Crosscut road and 100 feet road radiating from Gandhipuram attract large crowd due to shops, stores and other business establishments, and have corresponding high flow in vehicles (Plate 1 and Plate 2). Most of the roads that originate from Gandhipuram, which are either bound to state highways or other commercial lanes are narrow. The narrow roads obstruct free flow of traffic leading to high emission especially during peak hours.

2.5.3 Station C: Saibabacolony (Urban – Residential)

Station C is predominantly residential colonies, consisting mostly of high-income group (HIG) of residents. The state highway leading to Mettupalayam lies at about 200 m east of the sampling point. Except for the state highway, all other roads lying near the sampling point have very low volume of traffic. No conspicuous industrial activity is seen close to station C. Local sources of air pollution are mainly vehicles and diesel generators frequently used in the case of the electricity failure.

2.5.4 Station D: Small-scale Industries Development Corporation - SIDCO (Suburban -Industrial)

Station D is located in an industrial complex (Plate 3) owned by Government of Tamilnadu, Small-scale Industries Development Corporation (SIDCO). The total area of the industrial estate is 38.2 hectares located southwards from the Coimbatore city. The sampling station did not target any specific industry and was located almost in the middle of the estate to represent the whole estate. The sampling station is at about 30m from the state highway that leads to Pollachi and other far away places. In SIDCO there are about 227 industrial units employing more than 3600 people (Table 2.4), apart from a considerable floating population. Metal casting and founding industries is a major group of industries employing 27 % of total employees although the number of such industries are less than 20 (Table 2.4).

Engineering and machining industries are mainly involved in production of various accessories and machines required for textile machines, electrical pumps, motors and other machines. Plastic industries are involved in manufacturing polythene bags, pipes, joints etc. Main sources of air pollution in SIDCO are probably metal casting operations, cotton textiles and diesel generators used as power backups. Except the state highway there are no other roads of considerable traffic near SIDCO. The area is surrounded by residential colonies or waste lands. Except from industries, no other notable sources of pollution exist in Station D.

Table 2.4 Industries of SIDCO and number of workers

Industry	Textiles	Metal casting	Metal fabrication	Engineering and machining	Plastic	Others
Workers	231	1000	144	1569	168	497

2.5.5 Station E: Peelamedu (Suburban - Highway)

Station E lies at about 10-km east of the city railway station (Station B), near the National highway-47 at Peelamedu. Comparatively high volume of traffic (approximately 41124 vehicles/day), especially heavy-duty vehicles (Plate 4) is noticed near the sampling station, since the place is a major entry point to Coimbatore city. A few cotton textile mills, cotton-ginning mills lying within 2-km radius are the other major sources of air pollution here. Educational institutions occupy a large portion of land towards eastern side of the sampling station while the rest of the land almost lie waste. The civil airport is present at about 3-km east of the sampling point.

2.5.6 Station F: Kuniamuthur (Suburban/Rural - Residential)

Kuniamuthur lies at about 5 km from Coimbatore city towards its south. The national highway-47, leading to the Kerala State, passes through Kuniamuthur. The sampling point lies about 600 meters away from the highway amidst residential houses and wastelands. Although the sampling station is located close to the city, the place is predominantly an agricultural area. Few wetlands in and around Kuniamuthur occupy a major portion of land (Figure 2.2). Despite the presence of few medium scale textile mills, highway vehicular traffic is the conspicuous source of air pollution in Kuniamuthur. Occasional burning of agricultural wastes and debris may also contribute to it. This station was preferred as the industrial/urban activities that contribute to atmospheric pollution are less here compared to the other stations.



Plate 1 View of Gandhipuram at cross cut road junction

Plate 2 View of Gandhipuram at Sathy road junction

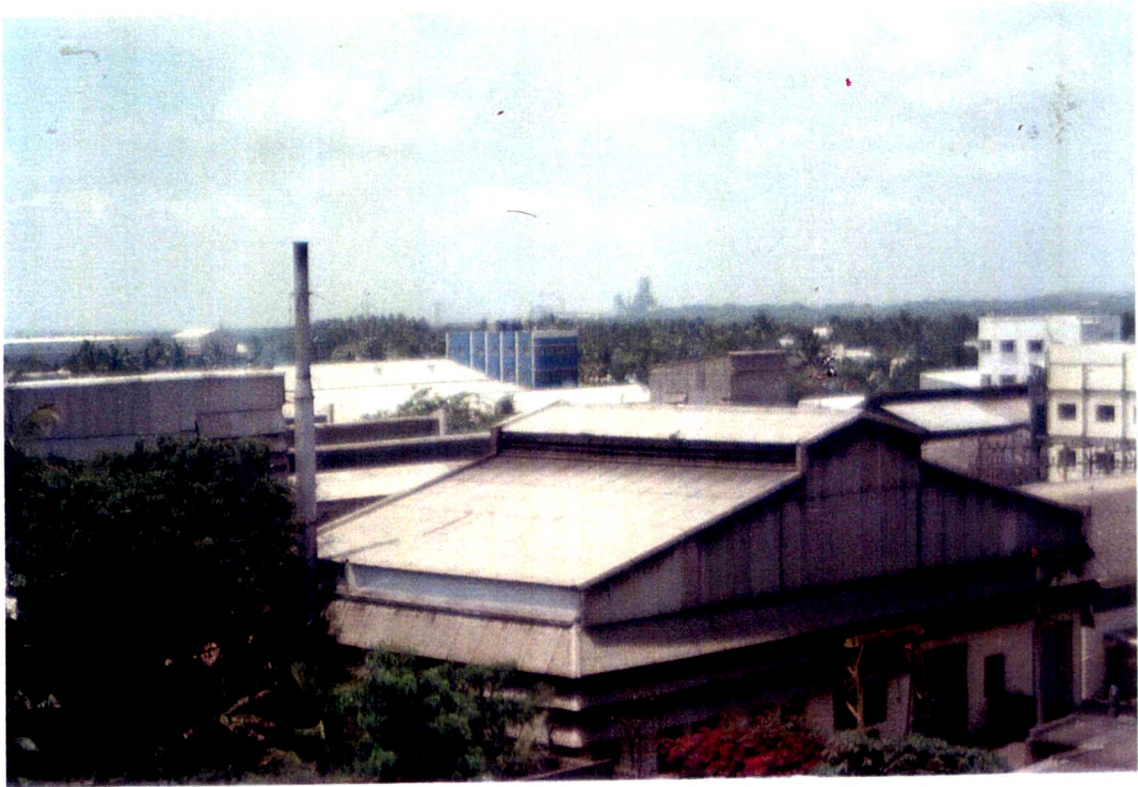


Plate 3 SIDCO Industrial complex

Plate 4 Heavy-duty vehicular traffic at station E

Chapter - 3

Micro Meteorology of Coimbatore

3.1 Introduction

Meteorology is an important factor contributing to air quality (Goudie and Cuff 2002, Seaman 2000, Spurr 1978). The nature and density of emission are influenced by meteorological conditions by their role in dispersion and dilution. It encompasses atmospheric processes that control or influence evolution of emissions, chemical species, aerosols and particulate matter. These processes influence horizontal and vertical transport, turbulent mixing, convection, and dry and wet deposition of air pollutants. Relative humidity, solar energy, temperature, and presence of liquid water droplets and clouds affect the rates at which secondary species of aerosols are formed.

Most of the severe air pollution episodes that resulted in mortality occurred mainly due to the meteorological conditions. Low wind speeds, low mixing heights and accompanying fogs favor the build up of primary pollutant concentrations. Lillis et al (1999) reported that high aerosol sulfate concentrations are associated with coastal fog and relative humidity. Their investigation on wet deposition in the San Joaquin Valley of California during winter showed that a typical fog removes 500-2000 $\mu\text{g m}^3$ of sulfate, 2500-6500 $\mu\text{g m}^3$ of nitrate, and 2000-3500 $\mu\text{g m}^3$ of ammonium (Lillis et al 1999). The net reduction of ambient concentrations due to fog deposition accounted to 0.05-0.2 $\mu\text{g m}^3$, 3-6 $\mu\text{g m}^3$, 1-3 $\mu\text{g m}^3$ for sulfate, nitrate and total ammonium respectively. Zee et al (1998) observed that urban and non-urban differences in the absolute concentrations of PM 10 mass, black smoke and non-organic secondary aerosols, depended strongly on wind direction.

3.2 MicroMeteorology of Coimbatore during study period (January 1999 – February 2001).

The following discussion on micrometeorology of Coimbatore is based on data acquired from the Tamilnadu Agricultural Univeristy (TNAU), Coimabatore. Coimbatore has more or less uniform thermal regime throughout the year. Summer in the district is during March to May. Summer is followed by southwest monsoon that starts in June and continues up to September. October and November constitute the post monsoon season characterized by the northeast monsoon. December to first half of February is the winter or coolest season.

The average minimum and maximum temperature ($^{\circ}\text{C}$) during the year January 1999 – December 1999 and January 2000 – February 2001 was 31.6 ± 3.1 & 21.1 ± 2.4 and 31.75 ± 2.5 & 21.2 ± 2.4 respectively (Figure 3.1). The highest (37.5°C) and the lowest temperature (10.5°C) during the study was in May 2001 and January 1999 respectively. After February temperature continues rising till May. Generally during March to June the maximum temperature is higher and the days are comparatively hot and dry. With the gradual onset of the northeast monsoon in October the weather becomes cooler. Days and nights during December and January are relatively coolest.

Relative humidity recorded during the study period is shown in Figure 3.2. Mornings in general are humid than afternoons, with the average humidity exceeding 77%. During September, October and November the afternoon humidity are comparatively higher. For rest of the year the afternoons are drier and during February to May the afternoons are driest. The ratio between the relative humidity in the morning and evening was low during the monsoon months.

According to the report of meteorological department (Climate of Tamilnadu 1999), as per the past record the normal annual rainfall in Coimbatore district is 1129.5 mm with average 55 rainy days. July during the southwest monsoon and October during the northeast monsoon are usually the rainiest months. During the study period in Coimbatore city, average of 71 annual rainy days were recorded. The annual rainfall was 598 and 625 mm during 1999 and 2000 respectively (Figure 3.3). The highest rainfall during the year 1999 was in October (306 mm), while during 2000 the highest was in September (210 mm).

During April to October the winds are light (monthly mean 1.5 – 9.1 km/hr), while May onwards wind speed increases progressively, with July recording highest wind speed during the study period (Figure 3.4). From May to October the winds blow mostly from south and southwest wind direction (Table 3.1). For rest of the year, majority wind is from north, northeast and east (Figure 3.5). Wind direction and typical air trajectory (year 2000) in various seasons over Coimbatore and its environs depicted in Figures 3.6 to 3.9. North easterlies appear in October and during November to March winds from northeast and east are the most predominant. South and easterlies appear in April.

The area gets good sunlight all round the year, the average solar radiation being 392.2 cal/cm²/day and cloud cover comparatively low. High variability in solar radiation was seen during the monsoon months (Figure 3.10) due to cloud cover. The average daily evaporation rate recorded during the study period was 5.18 mm. No significant variation in evaporation rate was observed between the study years (1999-2000: 5.13 ± 1.77 mm, 2000-2001: 5.2 ± 1.9 mm - Figure 3.11).

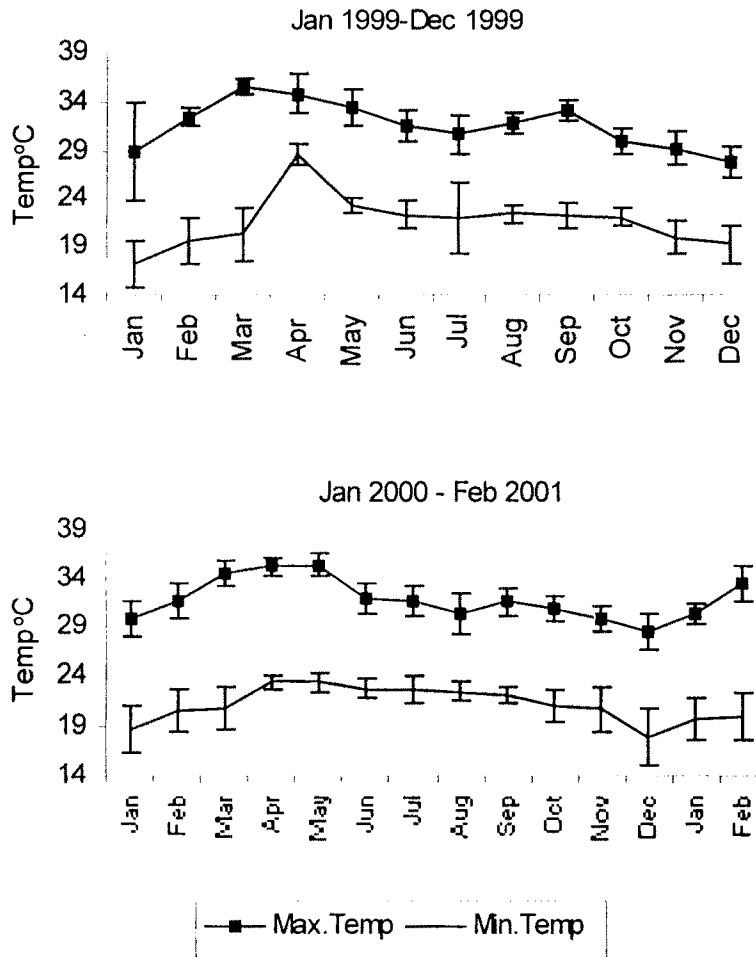


Figure 3.1 Maximum and minimum temperature recorded during January 1999 to February 2001

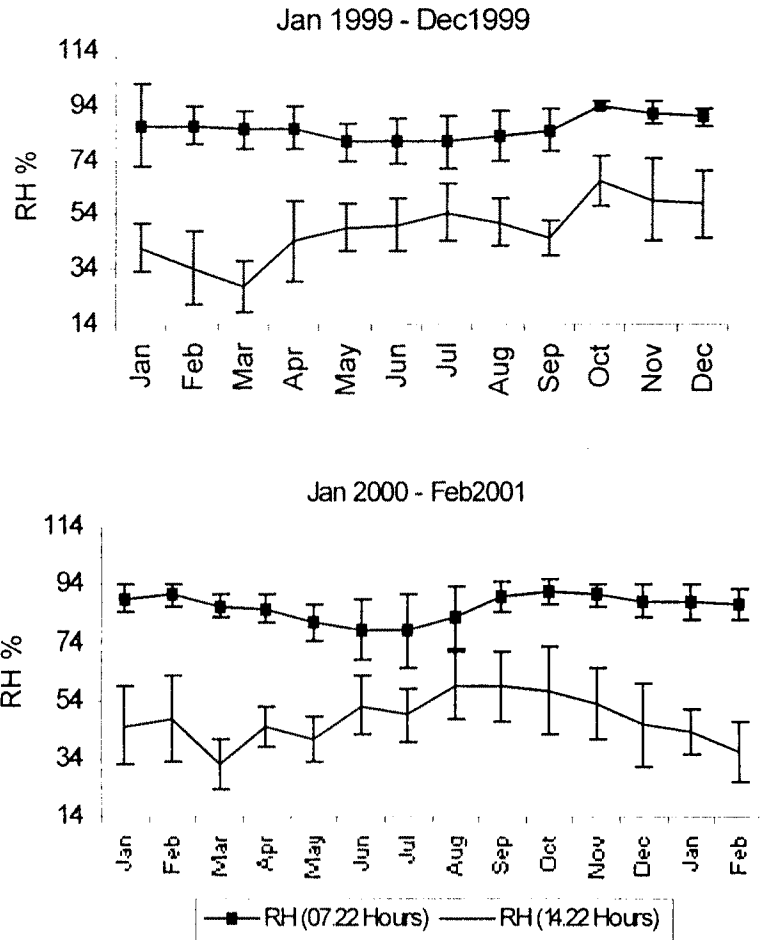


Figure 3.2 Relative humidity during January 1999 – February 2001

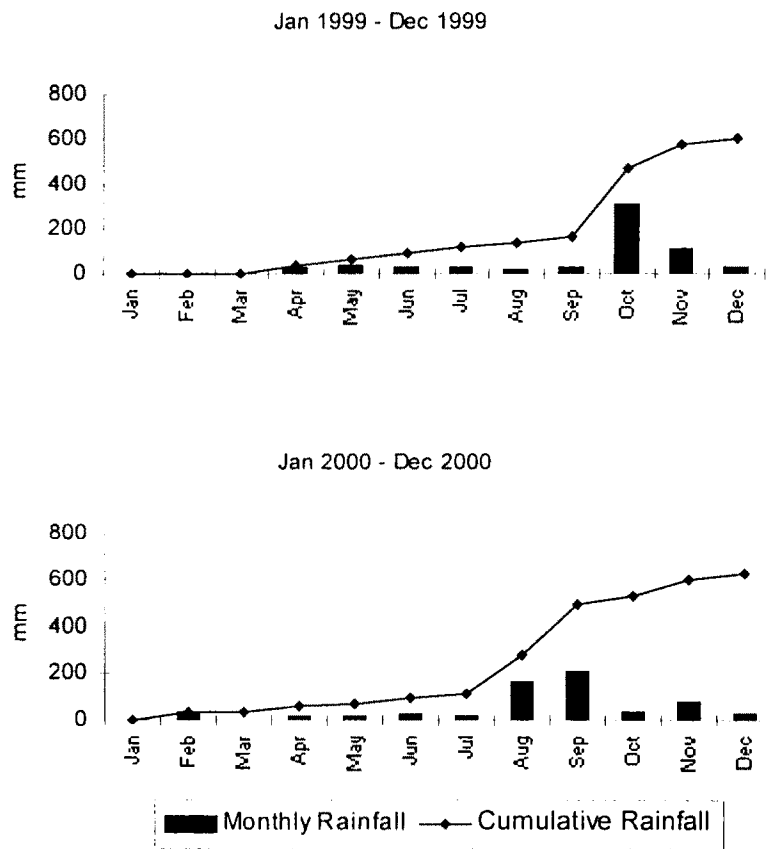


Figure 3.3 Rainfall (in millimeter) during January 1999 – December 2000

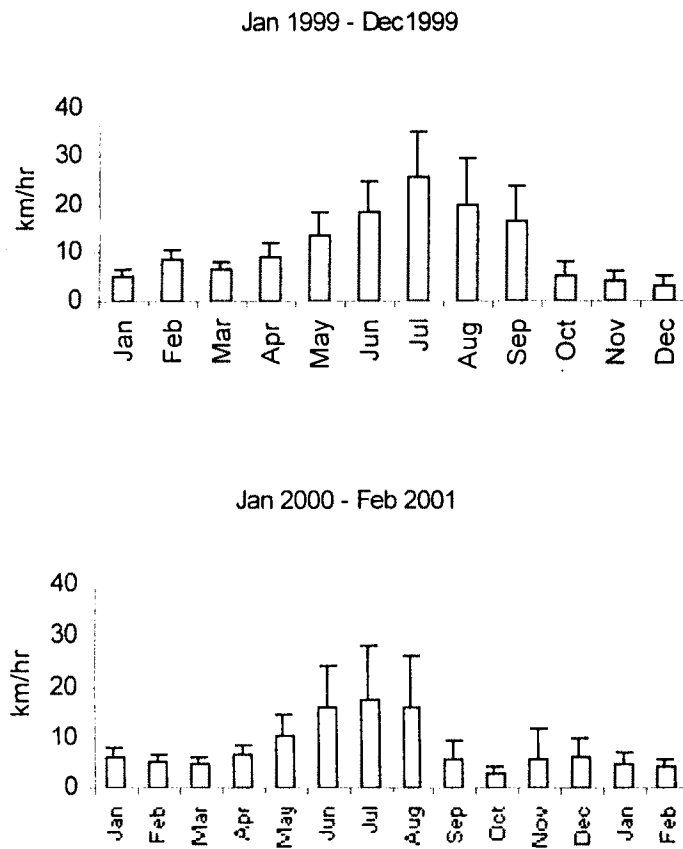


Figure 3.4 Wind speed during January 1999 – February 2001

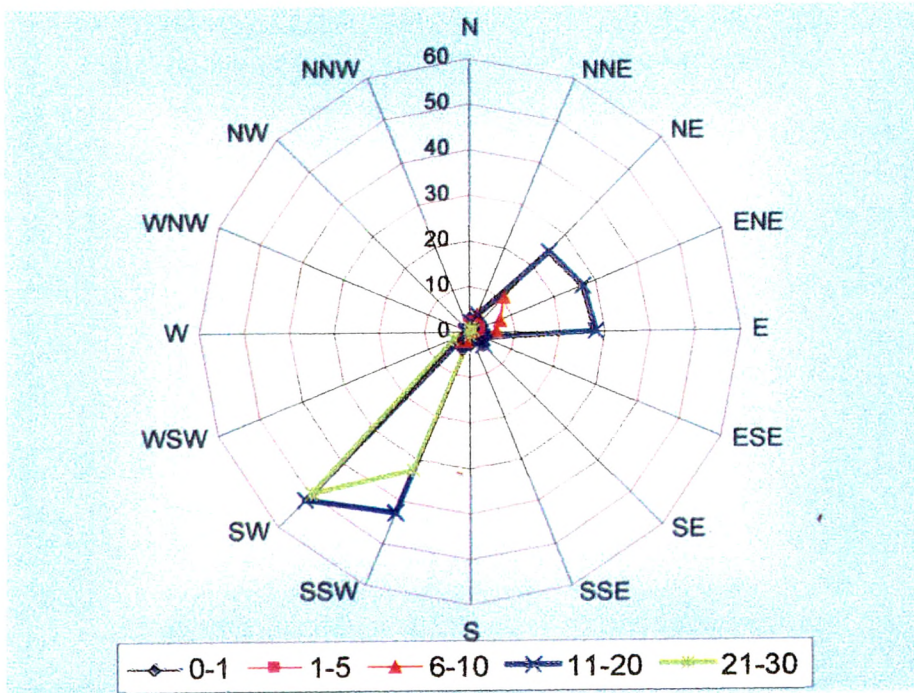


Figure 3.5 Wind direction and speed in the year 2000 (17.30 hrs)

Table 3.1 Average wind pattern in the year 2000

Direction	%
North	2
North North East	4
North East	11
East North East	11
East	11
East South East	2
South East	2
South South East	0
South	1
South South West	23
South West	29
West South West	2
West	1

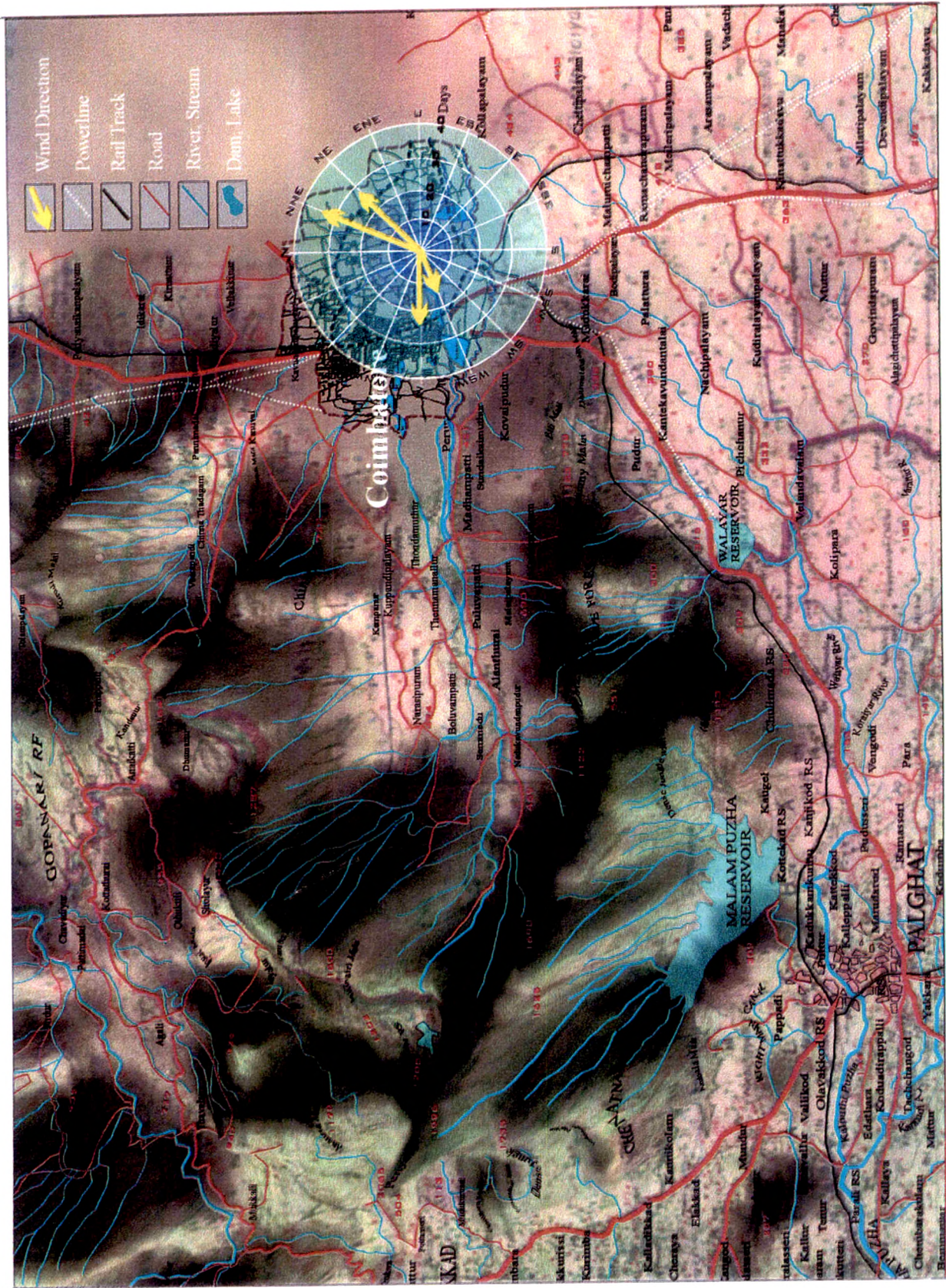


Figure 3.6 Wind direction during February to May 2000

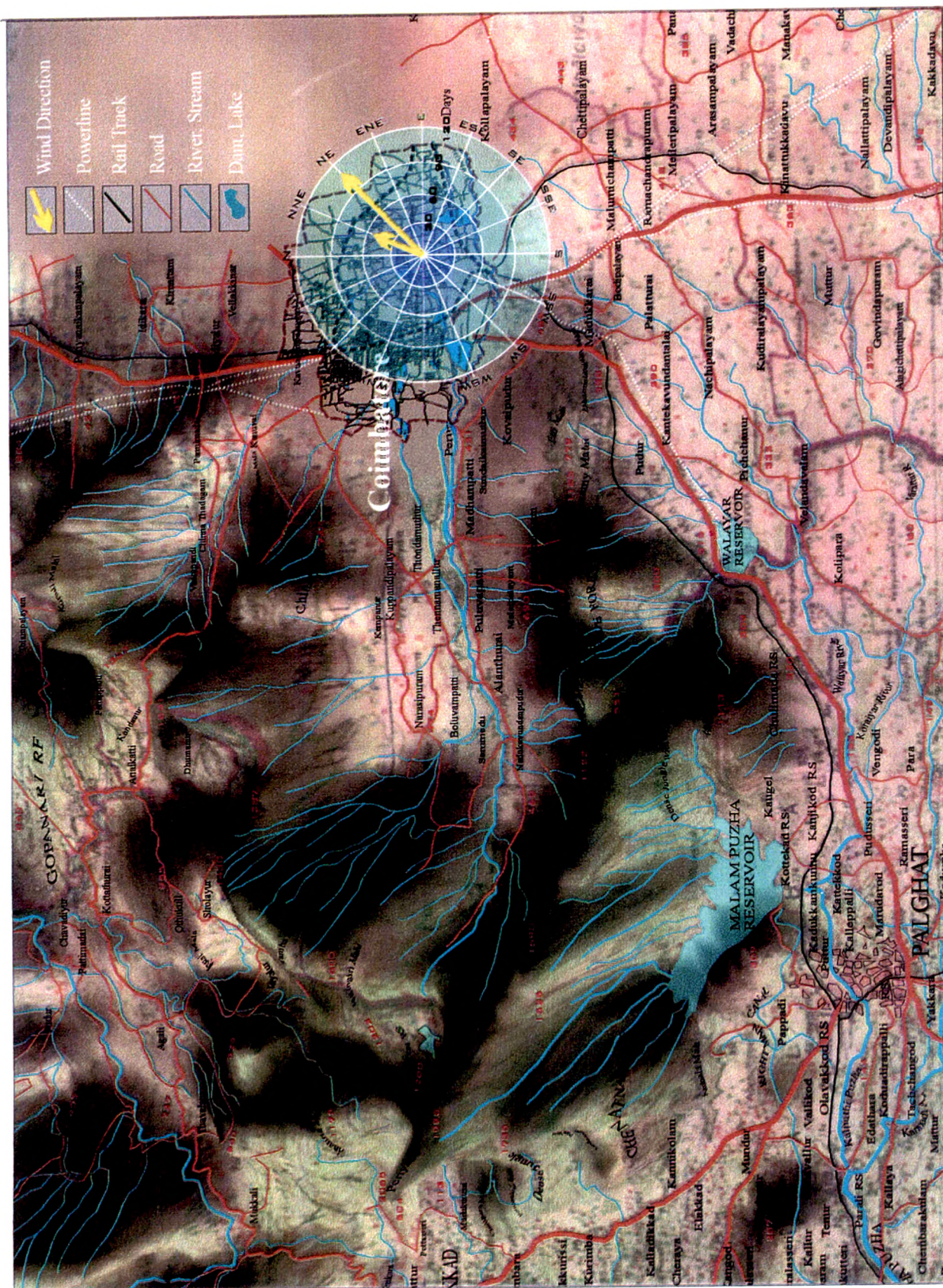


Figure 3.7 Wind direction during June to September 2000

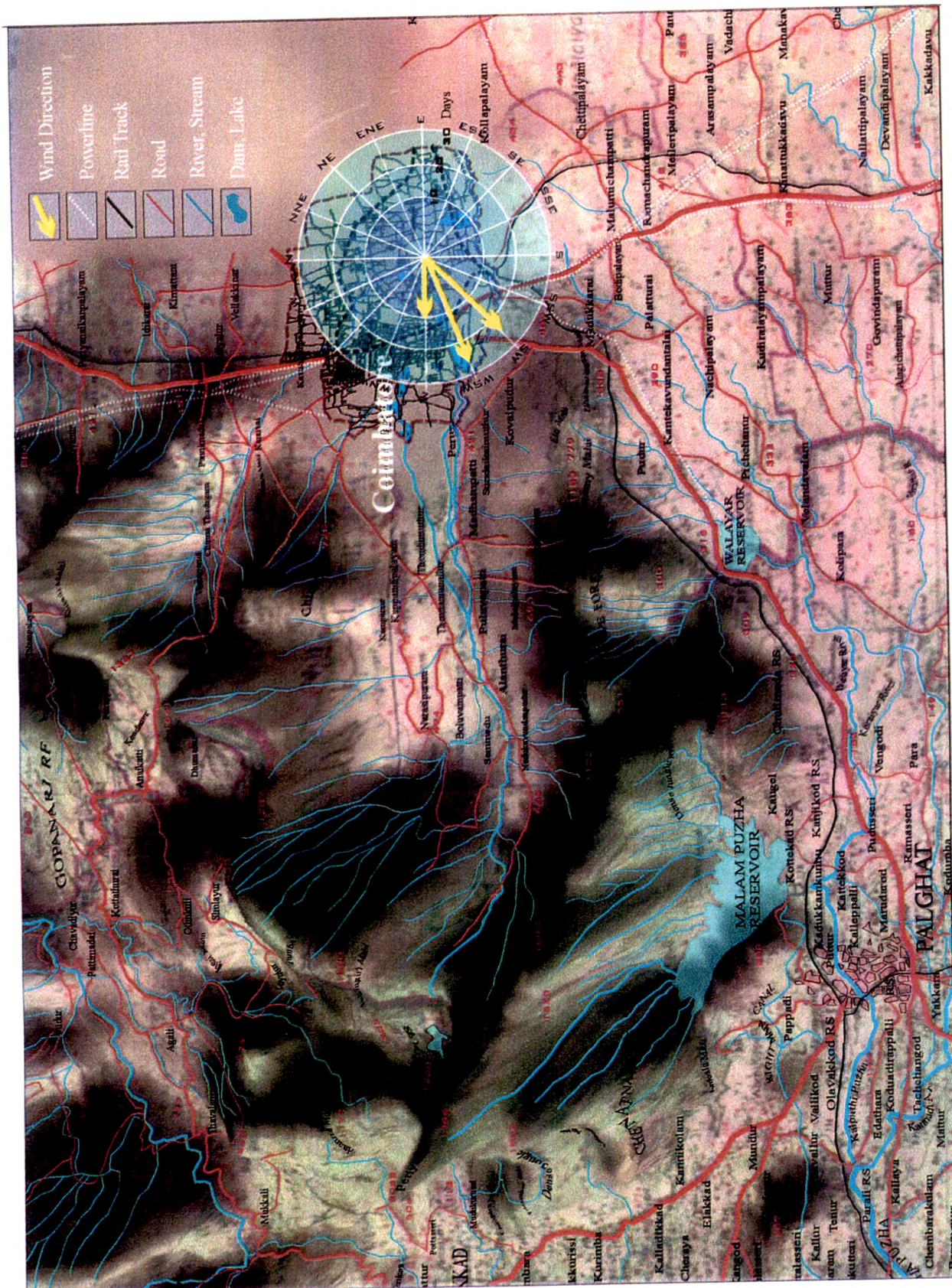


Figure 3.8 Wind direction during October to November 2000

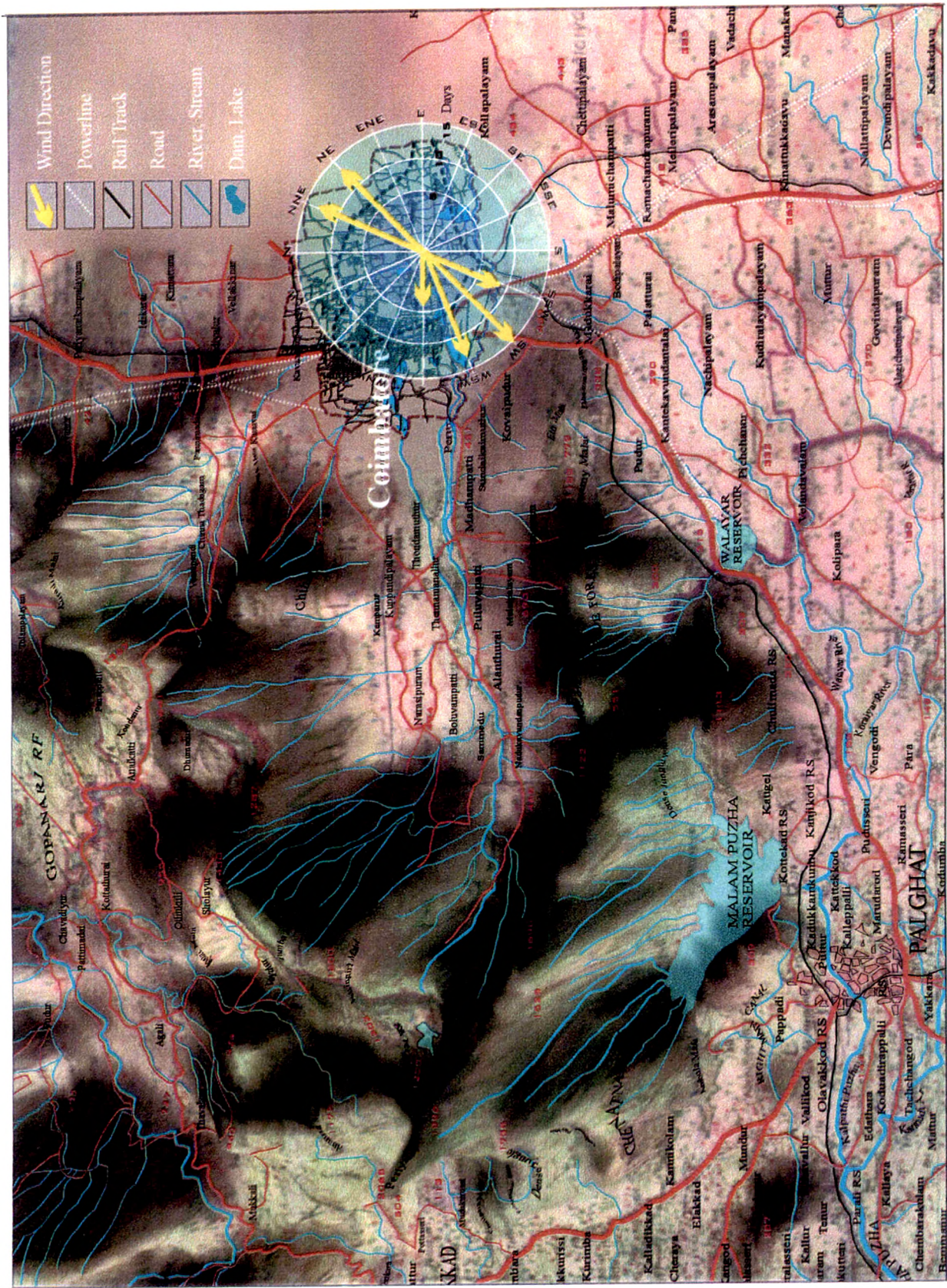


Figure 3.9 Wind direction during December to February 2001

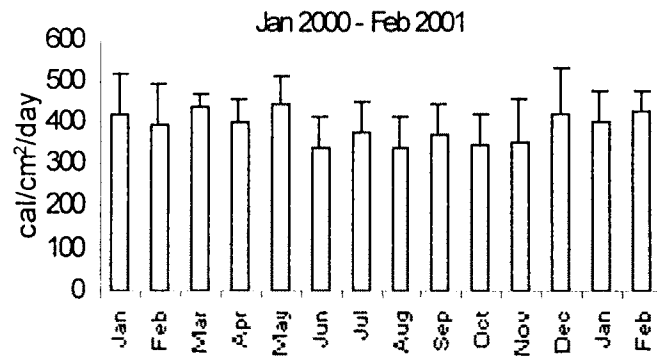
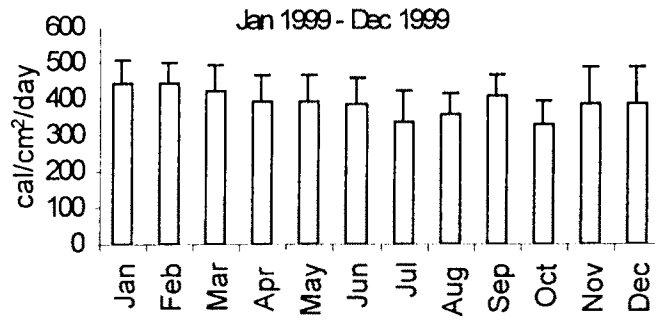


Figure 3.10 Solar radiation during January 1999 – February 2001

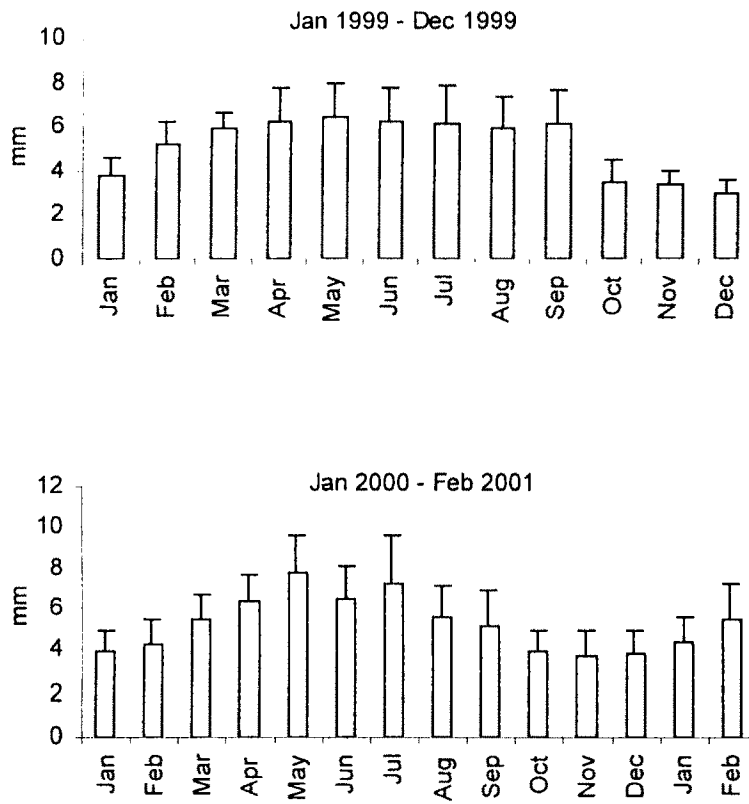


Figure 3.11 Evaporation during January 1999 – February 2001

CHAPTER – 4

Vehicular Traffic and Emission

4.1 Introduction

Transport plays a vital role in economic and human development. In the initial phases of development of an economy, transport requirements tend to increase at a considerably higher rate than the growth of economy (Sriraman 1998). In India, during 1950 to 1965, the rail freight traffic increased nearly two and half times and traffic by road almost five times. Regarding passenger traffic, road traffic increased almost three times. Recently it is reported that road traffic would account for 87% of passenger traffic and 65% of freight traffic. The increase in road traffic had direct implication on pollution. In Delhi, the vehicular pollution was increasing since 1971 (Table 4.1). During 1975 – 1995 vehicular pollution in India has increased by 7.5 times (Kumar and Bhattacharya 1999). Emission load in the metropolitan increased from 1450 tonnes in 1991 to 3000 metric tonnes in 1997.

Vehicular emissions such as SPM and gaseous pollutants from the growing vehicular fleet are major culprit in causing various health disorders in human being including lung cancer (Down to earth 1999 c). Vehicular traffic and roads are also known to cause a number of ecological effects (Spellerberg 1998). Above normal levels of heavy metals have been recorded in plants up to 150m distance from roads. Such high concentration of metals may cause physiological stress. Various other impacts such as road mortality, fragmentation of habitat and pollution of aquatic systems near road traffic due to run-off has received much attention from researchers in the recent decades. Current study discusses the vehicular growth and its emissions in Coimbatore.

Table 4.1 Percentage share of air pollution by various sources in Delhi

Pollution source	1970-71	1980-81	1990-91	2000-01
Industrial	56	40	29	20
Vehicular	23	42	63	72
Domestic	21	18	8	8

Source: <http://www.teriin.org>

4.2 Background

4.2.1 Vehicular growth in India

Since 1950, the global vehicle fleet has grown tenfold, and it is estimated to double again within the next 20-30 years (Mayer 1999). The global number of motor vehicles, excluding two wheelers, had been rapidly increasing since 1950 and is now above 600 million. In addition there is an estimated 80 million motorcycles (Fenger 1999). Much of the expected vehicle growth in the coming years is likely to occur in developing countries and in Eastern Europe.

In India, vehicle population has grown from 0.3 million in 1951 to almost 40 million in 1997- 98, more than a hundred-fold increase (Table 4.2). At the same time growth of road network in India was not maintaining a similar pace (Table 4.2). In the last 45 years the total length of roads in the country has increased only 7 times, while length of National and State Highways (which carry the majority of traffic) across the country has increased merely 1.7 and 2 times respectively. Lack of adequate investment in road infrastructure is common in any developing economy and India is not an exception. In 1948, Chennai (an important metro city in the country with an area of 172km²) had only a vehicle population of 6,000 cars and 810 two-wheelers. Today, after 50 years, with not substantial addition to road network, it has 3,00,000 cars and 4,00,000 two-wheelers. Elsewhere, in Mumbai and Delhi, traffic snarls due to road congestion allow vehicles to travel at maximum

speeds of only 12 and 22 kmph respectively ([http://www. goldwire.com](http://www.goldwire.com)) adding on the pollution load.

Table 4.2 Vehicular growth and growth of road network in India

Year	Road network (million km)	Vehicle population (in million nos.)	Passenger traffic (billion person km)	Freight traffic (billion ton km)
1951	0.4	0.3	23	6
1997	3.0 (7 times)	37.5 (125 times)	1500 (65 times)	400 (67 times)
2001	-	54	3000	800

Source: <http://www.cybersteering.com/pulmain/reports/infra.html>

In India, especially after the economic liberalization since 1991, the motor vehicles have been growing up more rapidly (Table 4.3). The total number of vehicles sold in 1983- 84 was 0.99 million, which increased to 2.2 million in 1991- 92, and in 1996 - 97 the number rose up to 3.97 million, indicating a compound average growth rate of 14.4% during 1991- 92 to 96 - 97, as compared to 9.4% during 1983 - 84 to 1991 - 92 (Bose and Sundar 2000). The vehicle mix is unique to India in with a very high proportion of two wheelers (76%). The rate of addition of two-wheeler to Indian roads is also faster. During the year 1996 registration of two-wheelers were 23,111,000. In 2000 the number went up to 36,298,000 showing 1.57 times increase in a very short span (Table 4.4). Table 4.5 gives the status, performance and life of Indian vehicles on roads.

Table 4.3 Vehicle population (x1000) in India (1991-1998)

Year	All type of vehicles	Two wheelers	Cars, Jeeps and Taxis	Buses	Goods vehicles	Others
1991	21374	14200	2954	331	1356	2533
1992	23507	15661	3205	358	1514	2769
1993	25505	17183	3361	364	1603	2994
1994	27660	18899	3569	392	1691	3109
1995	30295	20831	3841	423	1794	3406
1996	33783	23252	4204	449	2031	3847
1997	37231	25693	4662	488	2260	4128
1998	40939	28342	5056	535	2529	4477

Source: www.osc.edu/research/pcrm/emissions/partII.shtml

Table 4.4 Total registered population of two and three wheelers in India (units X1000)

Year	Two-stroke 2 wheelers	Two-stroke 3 wheelers	Four-stroke 2 wheelers	Four-stroke 3 wheelers	Total 2 wheelers	Total 3 wheelers
2000	32,014	1,678	4,284	394	36,298	2,072
1999	29,408	1,578	3,113	289	32,521	1,867
1998	26,958	1,446	2,159	211	29,117	1,657
1997	24,554	1,271	1,520	152	26,074	1,423
1996	21,955	1,099	1,156	109	23,111	1,208

Source: <http://siamindia.com/technical/emission.htm>

Table 4.5 Average service life and annual mileages of Indian vehicles

Vehicle type	Service life year	Annual mileage (kms)
2-Wheeler	15	10,000
3-Wheeler	10	40,000
Passenger car	20	15,000
Taxis	10	30,000
MUV	15	37,000
Trucks	15	40,000
Buses	8	30,000
LCV	5	60,000

LCV: Light Commercial Vehicle, MUV: Multi Axle Vehicle

4.2.2 Vehicular Emissions

The exhaust of an internal combustion (IC) engine of automobiles contain gases such as carbon dioxide (CO₂), carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NO_x), oxides of sulfur (SO₂), oxygenated hydrocarbons like aldehydes, smoke, soot, other forms of black carbon and particulate matter including lead and water vapor (H₂O). Emission inventories show that vehicular emissions, especially diesel emission are an important source of atmospheric particulate elemental carbon contributing 70-90% in cities with high vehicular traffic (Hamilton and Mansfield 1991). Motor vehicle emissions are highly variable and several factors are known to affect it (Nanjundiah 1998). Linnel and Scott (1962) in an analysis of diesel exhaust reported 114 – 483 µg/L

of particulate matter, 70-341 $\mu\text{g/L}$ of carbon and several other hydrocarbons such as acetylene, ethylene, propane, propylene, n-butane, 1-butene, 2-butene, iso pentane, butadiene etc, in varying concentrations with respect to Horse Power (HP) and RPM of the engine.

The main factors that influence the vehicle emissions are characteristics such as (i) vehicle size, age, engine type and technology (ii) mechanical condition of the engine and adequacy of maintenance (iii) emission control equipment and its condition (iv) fuel properties and quality and (v) operating characteristics such as altitude, temperature, humidity and driving patterns, traffic speed and congestion. Operating conditions can cause emissions from a vehicle to change by more than 100% (Table 4.6). Congestion of traffic is an important factor that enhances the vehicular emissions especially in developing countries. One of the most cited example is the problem in Bangkok, Thailand where an average car is estimated to spend 44 days per year stuck in traffic (Shah and Nagpal 1997). Indian conditions are more serious as vehicles of various types including bullock carts and cycle rickshaws use the same tracks/roads. A recent analysis (during 1994-1995) in UK shows that a small minority of high emitting vehicles contribute significant proportions to the fleet hydrocarbon emissions at all sites (Revitt et al 1999). It was also found that vehicles of 1985-1991 models are contributing about 52% the hydrocarbon fleet emissions.

Table 4.6 Typical values of emissions (in ppmv) under different operating conditions

Constituents	Idling	Cruising	Acceleration	Decelerating
CO	6400	24000	24000	45000
Hydrocarbons	1400	620	810	5700
NO	0	1400	1700	0

Table 4.7 Quantities of pollutants (giga gram) emitted from transport sector in India for the years 1990 and 1994

Species	Gasoline				Diesel			
	MC/SC		Cars		LCV		HCV	
	1990	1994	1990	1994	1990	1994	1990	1994
CO ₂	7020	7670	3780	4130	13950	17400	32550	40600
NO _x	5.2	5.6	24.2	26.5	456.4	569	2198	2741
CO	1352	1470	214.2	234	217.2	271	1710	2132
NMVOC	670	728	42	44	231.8	289	427.4	533

NMVOC = Non Methane Volatile Organic Compounds, MC = Motor Cycle, SC = Scooter, LCV = Light Commercial Vehicles, HCV = Heavy Commercial Vehicles.
(Source: www.osc.edu/research/perc/emissions/inventory.shtml)

Table 4.8 Estimated vehicular emission load in selected metropolitan cities

City	Vehicular pollution load (tonnes per day)					
	Particulates	SO ₂	NO _x	HC	CO	Total
Delhi	10.30	8.96	126.46	249.57	651.01	1046.30
Mumbai	5.59	4.03	70.82	108.21	469.92	659.57
Bangalore	2.62	1.76	26.22	78.51	195.36	304.47
Calcutta	3.25	3.65	54.69	43.88	188.24	239.71
Ahmedabad	2.95	2.89	40.00	67.75	179.14	292.71
Pune	2.39	1.28	16.20	73.20	162.24	255.31
Chennai	2.34	2.02	28.21	50.46	143.22	226.25
Hyderabad	1.94	1.56	16.84	56.33	126.17	202.84
Jaipur	1.18	1.25	15.29	20.99	51.28	88.99
Kanpur	1.06	1.08	13.37	22.24	48.42	86.17
Lucknow	1.14	0.95	9.68	22.50	49.22	83.49
Nagpur	0.55	0.41	5.10	16.32	34.99	57.37
Grand total	35.31	29.84	422.88	809.96	2299.21	3597.2

Source: <http://www.teriin.org>

Durbin et al (1999) in a field study (South coast air quality management district, SCAQMD, project, California) showed that 1.11% - 1.75% of the vehicles in light duty fleet emit visible smoke. The fleet of smoking vehicles composed mainly of older vehicles (8-18 years old). The contribution of light-duty smoking vehicles to the particulate emissions inventory in the SCAQMD is estimated to 0.51-0.81 tons per day. The emission estimates for 1990 and 1994 for India based on mass emission factors of CO, HC and NO_x for Indian driving conditions are reported by the Central Road Research

Institute, Delhi (Table 4.7). Table 4.8 shows the estimates of vehicular load in the metropolitan and other major cities of India. The dominance of Delhi in the country in terms of vehicular pollution is very distinct.

4.2.3 Emission Standards for Vehicles

Since India embarked on a formal emission control regime only in 1991, there is a gap with technologies available in the USA or Europe. Currently, India is behind Euro norms by a few years. However, emission norms are being currently aligned with Euro standards. Vehicular technology is also being accordingly upgraded. Vehicle manufactures are working towards bridging the gap between Euro standards and Indian emission norms. Liberalization and establishment of manufacturing facilities by a number of international automobile brands have provided a great impetus to the process. Euro I is effective from 1 June 1999 and Euro II from 1 April 2000 for private (non-commercial) vehicles in the National Capital Territory (NCT), that include Delhi and its satellite townships, and metropolitan cities (Table 4.9 to 4.11). Recent policy has suggested Euro III for 11 cities and Euro II in the rest of the country and Bharat stage II norms for two and three wheelers by 2005 (<http://siamindia.com/technical/emission.htm>, Saxena et al 2002). Euro IV is proposed in 11 cities and Euro III in the rest of the country to be implemented by 2010 (Narain et al 2002). Since April 1995 it is mandatory to fit catalytic converters in new petrol passenger cars sold in the metros of Delhi, Calcutta, Mumbai and Chennai along with supply of Unleaded Petrol (ULP). Availability of ULP was further extended to 42 major cities and currently it is available throughout the country.

Table 4.9 Emission standards with effective date for new petrol vehicles in India under type approval test (g/km)

Vehicle type	CO				HC	HC + NO _x		
	April 1991	April 1996	April 2000 (Euro I)	April 2005 (Euro II)	April 1991	April 1996	April 2000 (Euro I)	April 2005 ^a (Euro II)
Two-wheelers	12-30	4.50	2	-	8-12	3.6	2	-
Three-wheelers	12-30	6.75	4	-	8-12	5.4	2	-
Cars with CC ^b	-	4.34-6.20 ^c	2.72	2.2	-	1.50-2.18 ^b	0.97	0.5
Cars without CC	14.3-27.1	8.68-12.4 ^c	2.72	2.2	2.0-2.9	3.00-4.36 ^b	0.97	0.5

Source: <http://www.urban.htm>
a. proposed; b. catalytic converter; c. the range corresponds to the engine capacity stratified into three classes: up to 1400 cm³, 1400–2000 cm³, and over 2000 cm³.

Table 4.10 Emission standards for gasoline light duty vehicles (in gm/km)

Year	CO	HC	HC+NO _x
1991 (a)	14.3-27.1	2.0-2.9	-
1996 (a, b)	8.68-12.40	-	3.0-4.36
2000 (b)	2.72	-	0.97

a – Depends upon engine capacity; b-No crankcase emission; Evaporation emission 2.0 gm/test max (Source: www.osc.edu/research/pcrm/emissions/inventory.shtml).

Table 4.11 Emission standards for heavy diesel vehicles (in gm/kw.hr)

Year	CO	HC	NO _x	PM
1992	14.0	3.5	18.0	-
1996	11.2	2.4	14.4	-
2000	4.5	1.1	8.0	0.36

4.2.4 Pollution control standards for vehicles plying in India

As per the Central Motor Vehicles Rules-115 (II) 1989, the pollution standards laid down for carbon monoxide in petrol vehicle and smoke intensity in diesel vehicles are given in Table 4.12 and 4.13.

Table 4.12 Pollution control standards for vehicles plying in India

Vehicle Type	CO emission by volume (Idling)	Hartidge Smoke (HS) units
2 and 3 wheelers (Petrol)	4.5%	-
4 wheelers (Petrol)	3.0%	
Diesel vehicles	-	65 for urban areas and 70 for non-urban areas.

Table 4.13 Current emission standards followed for vehicles plying in Coimbatore

Vehicle Type	CO emission by volume (Idling)	Hartidge Smoke (HS) units
2 and 3 wheelers (Petrol)	4.5%	-
4 wheelers (Petrol)	3.0% new vehicles 4.5% for 5 years old	
Diesel vehicles	-	65 for urban areas and 70 for non-urban areas.

4.2.5 Fuel Technology

In 1996, Ministry of Environment and Forests (Government of India) formally notified fuel specifications. Maximum limits for critical ingredients like benzene level in petrol have been limited to 1% for petrol in 2000 in NCT and Mumbai. Benzene content in gasoline has been limited to 3% for other metros and 5% for the rest of country since 2000 (<http://siamindia.com/technical/emission.htm>, Saxena et al 2002). In the place of phase-wise upgradation of fuel specifications there appears to be a region-wise introduction of fuels of particular specifications. The high levels of pollution have necessitated eliminating leaded petrol, throughout the country. To alleviate the problem of high pollution in 4 metro cities 0.05% sulphur petrol and diesel has been introduced since 2000-2001. For the rest of the country, sulphur content has been reduced by 75% from 1% in 1996 to 0.25% in 2000. Recently recommendations were made to set standards for olefins, aromatics and oxygenates in petrol and polycyclic aromatic hydrocarbons in diesel in 2005 (Narain et al 2002). In Delhi, the commercial vehicles

including buses, taxis and 3-wheelers are being converted to Compressed Natural Gas (CNG) or Liquefied Petroleum Gas (LPG) operation to control emissions. The last bus running on diesel was phased out of service in Delhi in the first week of December 2002.

4.3 Methodology

The total number of all kind of vehicles registered annually in Coimbatore was obtained from Regional Transport Office (RTO). Despite our attempts to get data on annual recruitment of vehicles for a longer duration, we could obtain only for the period 1994 to 2000. In addition about 984 automobiles were examined for emission exhaust using Netel Chromotograph Gas Analyser cum Smoke Meter. The data on volume of traffic at important road junctions were either obtained from highways department or by conducting spot surveys.

4.4 Results

4.4.1 Vehicular growth in Coimbatore

In the wake of urbanization and industrialization in Coimbatore, the number of automobiles is rising particularly after economic liberalization. As on march 2000, the total number of vehicles registered in Coimbatore city has grown to 4,37,088 of which approximately 3,86,942 are two-wheelers. According to Regional Transport Officials, vehicle numbers started rising since 1990. The growth was drastic since 1994. Before 1994 annual recruitment was around 10,000. The number hiked up to 23,638 in 1994 and thereafter a steady increase is noticed in the annual recruitment (Table 4.14). During the period 1994 to 2000 vehicular population increased 2.4 times. Currently around 38,000 vehicles are added to the Coimbatore roads every year. Table 4.15 shows the volume of traffic at various roads in Coimbatore.

Table 4.14 Annual registration of vehicles in Coimbatore (1994 –2000)

Vehicle type	1994	1995	1996	1997	1998	1999	2000	Total*
Taxi	93	135	210	116	107	51	121	860
2 Wheeler	12391	20685	25664	15584	26179	26258	29473	156616
3 wheeler	52	121	165	206	276	211	157	1219
Cars /jeep	1023	1912	2367	3124	3441	3073	3676	19045
Goods Vehicle	405	507	633	749	676	481	557	4112
Others	90	157	330	883	335	88	95	2058
Bus	17	121	237	299	267	58	60	1068
Total	14071	23638	29606	20961	31281	30220	34139	184978

* Total recruitment of vehicles during 1994 – 2000

Table 4.15 Vehicular movement in Coimbatore

Place	Type	Year of survey	Two-wheeler	Cars, jeeps	Buses	Lorries, LCV	Total
Athupalam ^s (F*)	NH	1999	6036	5816	5586	6578	24016
Athupalam [#] (F*)	NH	2002	8435	8400	5735	7300	29870
KMCH ^s (D*)	NH	1999	8946	6450	3740	5725	24861
Hopes [#] (E*)	NH	2000	17562	9870	7547	6145	41124
Podanur-Vellalur ^s	SH	1999	597	216	123	600	1536
Mettupalayam road [#] (C*)	SH	1999	12564	5790	3360	6439	28153
Thadagam road ^s	SH	1999	3846	1542	2760	4312	12460
Pollachi Road [#] (D*)	SH	1999	4698	3119	2698	4506	15021
TNAU - Maruthamalai road ^s	CR	1999	2200	824	464	1254	4742
Singanallur-Peelamedu ^s (E*)	CR	1999	2601	740	352	1694	5387
Valankulam bypass ^s (A*)	CR	1999	1647	2701	140	4836	9324

Spot survey, * Near the corresponding sampling station, \$ Data from highway department, NH-National highway, SH-State highway, CR-City roads. LCV Light Commercial Vehicle

4.4.2 Vehicular emissions of Coimbatore vehicles

Among 984 automobiles examined for vehicular exhaust 71% were two-wheelers, 17% were light duty cars and jeeps, and 12% were heavy-duty vehicles such as bus, lorries and public carriers of passengers or goods. Irrespective of the vehicle type, about 20% of the vehicles examined in the study failed to comply with currently followed emission norms

in Coimbatore (Figure 4.1). Within the two-wheeler sector, 38% of scooters exceeded the emission norms, followed by moped (16%) and bike (8%). Among the 8% of the bikes that failed to agree the emission norms, very few bikes (5) exceeded the HC emission limit of 2000 ppm, while others were found exceeding only the CO limit. Mopeds of 50-75 cc capacity are also plying on the roads in large numbers. Of the 217 mopeds tested for emission about 10% and 6% were found exceeding the limits for CO and HC respectively. Among the light duty petrol cars, all those exceeding the emission norms are more than 5 years old. Similarly in the case of diesel cars and jeeps, only old models exceeded the Hartidge Smoke (HS) limit of 65 units for urban areas.

Among the 553 two wheelers that were within the permissible limit 117 were with four stroke engines and the rest 2-stroke engines. Figure 4.2 depicts the range of CO% emission in two-wheelers of 4-stroke and two-stroke engines and petrol cars that comply the emission norms.

Among the light duty petrol cars about 52% that comply the emission levels are found with CO% emission in the range 2.5 – 4.5%. About 68 light duty diesel cars and jeeps that satisfied the emission (65 HSU) norms if grouped under 40 – 55 HSU and 55 – 65 HSU, a ratio 1: 3.2 among them was observed. In a similar grouping, the ratio for light commercial vehicles (totaling 53) was 1: 6.5 and Heavy vehicles (totaling 13) 1: 1.6, indicating that a majority of commercial vehicles may exceed the emission standards in future if not maintained properly.

Emission inventory for Coimbatore estimated based on the present vehicular population, growth and average annual mileage is shown in Table 4.16. The emission rate for the vehicles was adopted according to Saxena et al (2002) and Biswas and Dutta (1994). In

the case of two-wheelers, emission rate for 4-stroke and 2-stroke engines were estimated separately by following a recent assessment by Saxena et al (2002). Higher hydrocarbon (HC) emission load is obtained for two-stroke engines that has comparatively higher emission rate (HC = 3.34 gm/km) than four stroke engines (0.72 gm/km).

Table 4.16 Emission inventory for Coimbatore for the year 2001 (in x 1000 kg)

Vehicle type	HC	CO	N0x	PM
Two-wheelers with two stroke engines	11222.4	6753.6	100.8	840
Two-wheelers with four stroke engines	604.8	1570.8	604.8	
Auto rickshaws	292.25	175.875	2.625	
Petrol cars	382.32	992.97	382.32	175.3
Diesel cars and jeeps	132.16	519.2	467.28	944
Heavy duty diesel vehicle	472.5	2857.3	4725	675
Total emissions	13106.43	12869.75	6282.85	2934.3

4.4.3 Road transportation and accidental deaths in Coimbatore

In India road way human deaths are higher than many countries amounting to 60000 fatalities per year (Shah and Nagpal 1997). In the state of Tamilnadu, Coimbatore is second only to Chennai. During the year 1997-2000, about 776 people died, 5515 injured within the urban limits of Coimbatore. Among the deaths 22% were pedestrians, 18% were motorcyclists, 17% cyclists and rest traveling in other vehicles (Figure 4.3).

4.5 Discussion

Among the total vehicles recruited per annum in Coimbatore, 84.2 % were two-wheelers. The vehicular mix in India is also similar with 76% of the total vehicles in the country being two wheelers. The two-wheelers started growing rapidly ever since the introduction of 100cc bikes produced in collaboration with Japanese industries and the financial organizations offering various hire purchase schemes. With the direct entry of more multinational automobile manufacturers in India, the increasing purchase power of the

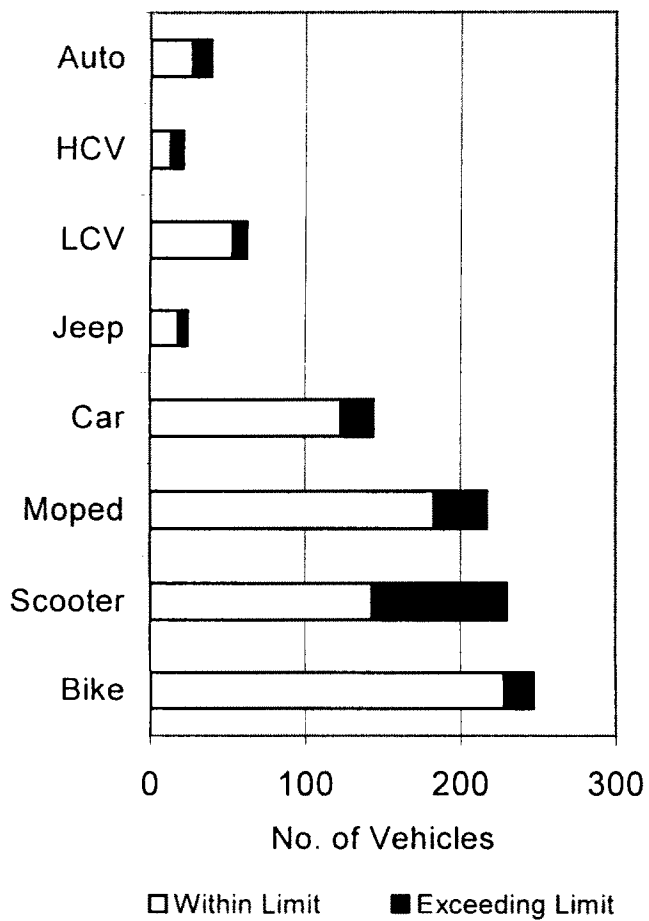
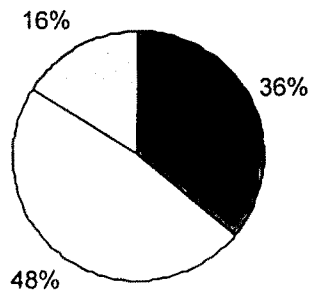
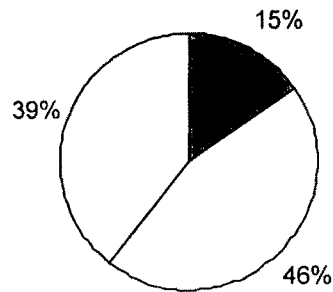


Figure 4.1 Emission status of vehicles examined in Coimbatore

CO emission range in 4-stroke engines



CO emission range in 2-stroke engines



CO emission range in petrol cars

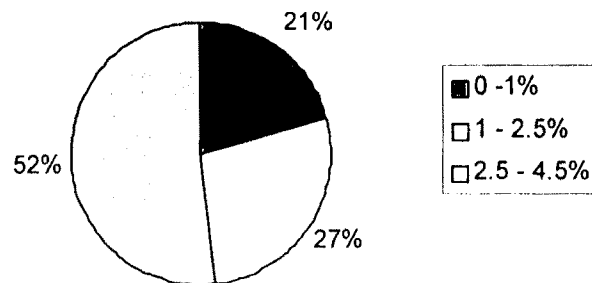


Figure 4.2 Classification of petrol vehicles (complying norms) according to their CO emission

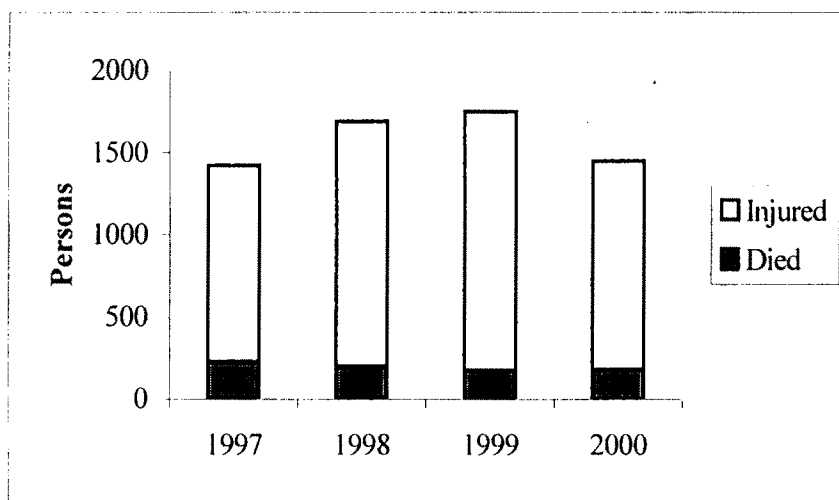


Figure 4.3 Road accidents and injuries in Coimbatore during 1997-2000

middle class and falling interest rates on loans, the pace in vehicular growth is further expected to increase. Till the last decade scooter occupied an enviable position as the vehicle of transport for middle class nuclear family. Recent years have seen small cars occupying the position. Scooters have almost lost their position to bikes as a means of personal travel to youths, youngsters and middle aged people.

In Coimbatore, apparently 80% of the bikes that do not comply the emission norms were of 2-stroke engines. In the case of scooters all that exceeded the emission limits were 2-stroke engines and 71 % of them were more than 5 years old. In the case of bikes, the introduction of 4-stroke engines had resulted in less polluting vehicles. Scooter manufacturers have also recently introduced 4-stroke engines. Among light duty petrol and diesel cars and commercial vehicles, a majority that exceeded the emission norms were 5-year-old vehicles. It has been estimated that at any point of time, new vehicles comprise only 8% of the total vehicle population. Hence the introduction of new vehicles with advanced emission control technologies could alleviate the problem of air pollution from vehicular source only to an extent. Emission levels of 39% of two-stroke engine driven two-wheelers in Coimbatore that fall in emission range 2.5 – 4.5% CO, if not maintained properly may later fall into the category of those exceeding the emission norms. In 4-stroke engines category, only 16% were within the emission range 2.5-4.5%, while rest of them that comply the norms were found with emission levels less than 2.5% of CO. This shows comparatively better performance of four-stroke engines. According to Roychoudhury (2000) a small fraction of badly maintained vehicles with technical flaws contribute disproportionately to air pollution. An analysis of vehicle emission in Pune showed one-fifth of the four wheelers tested contribute 40% of the carbon

monoxide and two-fifth contribute nearly 70%. The analysis also implied that 40% of vehicles contribute to nearly 70% of the pollution load.

Traffic congestion due to inadequate expansion and network of roads exacerbates the problem of vehicular pollution. In Coimbatore the total length of city roads is 683.5 km of which the national highway (NH-47) is about 20 km and state highway 70 km (Satyamurty 2000). The main arterial roads that radiate from Coimbatore are Palghat, Trichi and Avinashi roads. Most of the municipal corporation roads and panchayat roads in the city and its environs were unplanned creations that were made for the then transport means such as low speed vehicles, bullock carts, hand carts and bicycles. Some of these roads were expanded to cope with the growth of vehicles without any modification in basic structure. All these major roads contain many narrow bridges and invisible road junctions that poses immense problem to the movement of vehicles and are very conducive for accidents. Absence of traffic signals in some places and chaotic parking of vehicles obstructs the free flow of vehicles. The conditions of city roads are also very dismal with innumerable potholes and road damages. Manholes in the middle of certain roads are either in bad shape or steeply elevated from the road. Frequent braking of vehicles near such manholes leads to traffic congestion and higher emission. Absence of bus bays in Coimbatore city also adds to traffic congestion considerably.

Slow moving vehicles such as tractors, bullock carts and handcarts use the same roads hindering the traffic. Most of the auto rickshaws in the city are very old (more than 15 years) and hence their emission levels are also high.

During rainy seasons substantial quantity of dust/soil easily reaches the road from unpaved shoulders due to movement of vehicles. Resuspension of road dust due to traffic flow is a major source of airborne dust in Coimbatore city. Dropings from the vehicles carrying garbage, sands and other rubbish substances also make the roads very untidy.

Unhealthy practices of drivers of public transport like stopping the buses in the middle of the road and undisciplined driving is still prevalent in the city. Over acceleration and frequent braking by drivers of public buses and other commercial vehicles is another common scene that enhances the emission levels.

In urban areas, increase in traffic volume, absence of traffic signals, traffic congestion, road damages, narrow bridges and over crowding could add to high accidents (Shah and Nagpal 1997). In Coimbatore, such accidental deaths are common (Figure 4.3).

During the year 2000 and 2001 although many traffic signals were installed at several road junctions and bus stops in Coimbatore most of them practically are nonfunctional. Some of the narrow roads were expanded to facilitate the free movement of vehicles. Attempts were also made to streamline bus stops and stands within the city limits by the authorities to avoid traffic congestion. A major bye-pass road for NH-47 was built for a stretch of about 25 km. But for the new bye-pass road, all the heavy vehicles bound to other states and cities had to pass through Coimbatore city. Although some of such developments have currently reduced the pressure of vehicular growth to an extent, a lot more have to be done in this direction.

Parking and non-parking areas may be clearly defined and streamlined. Such measure may reduce the traffic congestion in commercial areas. Traffic congestion points can be identified and substantial expansion of roads in such points would facilitate the free flow of traffic. Quality of roads may be improved and periodically maintained to remove potholes and ditches. It has been estimated that improvements in roads will result in savings about 15% of vehicle operation costs. A need to develop an environment friendly and technically proper driving practices is also a need of the time. Drivers should be made aware that vehicular emission as a major contributor to air pollution. Especially drivers of public transport buses and goods carriers may be educated regarding driving disciplines in a manner to minimize traffic congestion. Drivers may be advised not to over accelerate the vehicles while moving inside the city and while idling in traffic signals.

Currently in India, only the transport vehicles that are used for hire or reward are required to undergo periodic fitness certification that includes emission level monitoring apart from other types of fitness checking. The large population of personalized vehicles are not yet covered by any such mandatory requirement. In the case of two-wheelers, except in metro cities and other urban centers, there is no statutory requirement for periodical emission checking. Apart from the fuel technology and vehicle technology, measures such as periodical emission checking for 2-wheelers and personalized cars should be made mandatory. Use of CNG and LPG as fuel in cars and auto-rickshaws can be promoted, since CNG is known to emit less particulates.

Apart from above discussed measures some other initiatives such as, simple traffic

engineering interventions (coordinated signals, reversible lanes, one-way street pairs, and other traffic control devices) to traffic restraints (area licensing schemes, parking controls, exclusive pedestrian zones, vehicle bans, special bus and high occupancy vehicle lanes and so on), advanced area traffic control techniques, and provision of facilities and services to encourage modal shifts (such as sidewalks, bicycle lanes, light and rapid rail transit, and commuter rail) may also be explored. These measures would require a policy framework encompassing regulatory, pricing, and taxation mechanisms, reinforced with effective enforcement, to encourage use of clean vehicles and fuels, to restrict or ban the use of polluting vehicles and fuels, and to modify travel behavior and transport demand (<http://www.teri.res.in>).

Technical solutions such as using catalytic system that provides vehicle combustion chamber with an adequate amount of cerium oxide (CeO_2) proved to be effective by Nikolaou (1999) in reducing pollutant emissions without affecting the parameters of the engine might also be worth exploring in the automobile sector. Currently there is a need for an integrated, holistic approach for controlling vehicular emission. Automobile and oil industry although had initiated a primary drive for cleaner fuel and emission reduction, public and civic authorities should take a significant role in curbing vehicular pollution.

4.6 Summary and Conclusion

In the current study, data regarding vehicular type and growth in Coimbatore was collected from Regional Transport Office (RTO) and vehicular emission exhaust was examined using Netel Chromotograph Gas Analyser cum Smoke Meter for petrol and

diesel driven vehicles. As on march 2000, the total number of vehicles registered in Coimbatore city has grown to 4,37,088 of which approximately 84.2 % are two-wheelers. About 20% of the vehicles examined in Coimbatore during the study failed to comply with currently followed emission norms. Light duty petrol cars and most of the diesel vehicles that exceeded the emission norms are more than 5 years old. Among two-wheelers those with four-stroke engines showed less pollution.

Although innovation in vehicle and fuel technology to curb emission levels are initiated in India since 1992, further measures recommended for betterment of Coimbatore environment. Periodical emission checking for two-wheelers and four-wheelers may be made mandatory. Auto rickshaws and lorries that are more than 15 years old may be either removed from the road or strictly instructed for upgrading the engine technology. Expansion of narrow bridges and certain roads such as Mill Road, NH Road, Sukrawarpet Road, Mettupalayam Road, Thadagam Road, Nanjappa Road, Crosscut Road may reduce the pressure of traffic congestion. Quality of roads may be improved and maintained well to remove potholes and pits. Parking and non-parking areas may be clearly defined and streamlined. Such measure may reduce the traffic congestion in commercial areas.

Resuspension of road dust is an important contributor for particulate matter in Coimbatore city, which can be minimized by periodical removal of dust form road. During rainy seasons more care should be taken to remove such dust. Flow of storm water on to the tarmac add fugitive dust emissions as road dries after a brief swell of rain. Bye-pass roads and ring roads may be planned in near future to contain traffic pollution.

CHAPTER-5

Suspended Particulate Matter

5.1 Introduction

Among the air pollutants, Suspended Particulate Matter (SPM) refers to the solid or liquid particles or combination of both that remains suspended in the atmosphere (Bragg and Strauss 1981, Faith and Atkission 1972, Lippmann 1998, Rao 1991). SPM may be further classified into dust, smoke, fumes, mist, fog, haze etc. Particulate matter (PM) that is 10 μm or less in diameter refers PM 10 or Respirable Suspended Particulate Matter (RSPM). PM 10 is generally subdivided into a fine fraction of particles 2.5 μm or less (PM 2.5), and a coarse fraction of particles larger than 2.5 μm (CEPA 1998, Rombout et al 2000). The fraction with aerodynamic diameters approximately below 0.15 μm is called ultrafine particles. Particulate matter is further classified as primary (emitted directly into the atmosphere) or secondary (formed in the atmosphere through chemical and physical transformations). The principal gases involved in secondary particulate formation are sulphur dioxide (SO_2), nitrogen oxides (NO_x), volatile organic carbons (VOCs) and ammonia (NH_3). Primary particles are found in both the fine and coarse fractions, whereas secondary particles, such as sulphates and nitrates, are found predominantly in the fine fraction. Both primary and secondary PM can result from either natural or anthropogenic sources.

Ever since the onset of industrialization and urbanization air borne SPM has been a major problem due to its adverse effects such as visibility reduction, soiling of buildings (Hamilton and Mansfield 1991, Pesava et al 1999, Scinfeld 1975, Williamson 1973) and impact on human health (Dockery et al 1992, Dockery et al 1993, Ortega-Rubio 1998, Pope III et al 2002). However, the serious nature of the issue was not realized till a few decades ago. Currently, most cities worldwide suffer from serious air quality problems

due to increasing urban population, combined with change in land use and vehicular traffic (Mayer 1999).

5.2 Background

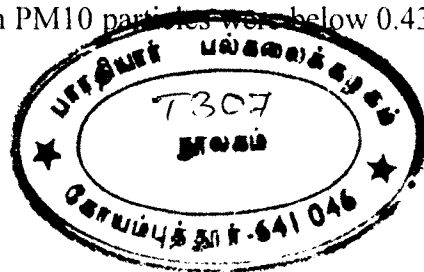
5.2.1 Size range and source of SPM

SPM are generally grouped in three modes; ultrafine, fine and coarse (Fenger 1999). The ultrafine particles of size range less than $0.1\mu\text{m}$, are formed by nucleation, that is, condensation of low vapour pressure substances formed by high-temperature vaporization or by chemical reactions in the atmosphere to form new particles (nuclei). They are mainly of anthropogenic origin such as from automobile exhaust, wood smoke and emission from diesel engines and generators (Lipmann 1998, Kleeman et al 1999, Shi et al 1999). Fine particles of size range $0.7\text{-}1\mu\text{m}$ are formed by accumulation or coagulation of ultra fine particles. In the close vicinity of the road, contribution of traffic to fine particle concentrations was 58-68% (Wrobel et al 2000).

Biomass burning is another important source of fine organic aerosols (Simoneit and Elias 2000). Coarse particles are larger size fractions (dust) containing solid particles of size ranging from $1\text{ to }200\mu\text{m}$ that are predominantly rock or soil of natural origin emitted into the atmosphere by mechanical grinding or spraying. These particles can include wind-blown dust from agricultural processes, uncovered soil, unpaved roads or mining operations. Traffic produces road dust and air turbulence that can re-entrain road dust. Near coasts, evaporation of sea spray can produce large particles. In urban atmosphere, dust arises due to agitation of soil through activities such as vehicular movement (Miranda et al 2000), and construction and earth moving (Gamble 1998). An estimated 80% of coarse particles from traffic in urban environment settles within 150m distance

from the road, ~ 40% at 200-27-m, and ~20% at 1500m (Wrobel et al 2000). In urban and suburban areas of Korea, soil re-suspension, fuel combustion, motor vehicles and secondary aerosols are identified as major sources for ambient SPM (Baek et al 1997).

According to Harrison et al (1997), PM10 fraction that causes significant health impacts is dominated by particles from 3 sources. (i) Primary fine particles from industrial and combustion sources, predominantly road traffic. (ii) Secondary aerosol, mostly ammonium sulfate and ammonium nitrate formed through photochemical reactions and (iii) Wind-blown soil and resuspended street dust present largely in coarse fraction (2.5-10 μ m). The coarse particles make a significant contribution to the particle mass, with coarse particles showing seasonal variation from about 20% of the total PM 10 mass in winter to 50% in the summer reflecting the impact of dryer summer climate on the re-suspension process. In urban atmosphere Miguel (1999) found re-suspension of paved road dust contributing up to 25-63% of the PM 10. In UK atmosphere, Clarke et al (1999) reported that on an average 10-20% of the mass of urban PM10 particles were below 0.43 μ m and 50 percent below 1.5 μ m.



5.2.2 Removal of atmospheric SPM

Once released into the atmosphere, particulate matter of smaller sizes has a longer residence time in the atmosphere. Elimination of these particles happens by both wet and dry deposition mechanisms. In wet deposition, incorporation of aerosols occur within cloud or below cloud and its efficiency is dependent on particle size and hygroscopicity of aerosols (Harrison and Alen 1991). The type of cloud and precipitation intensity is also expected to have a major influence. Rain effects about 90% removal of these pollutants than dry deposition mechanisms like gravity settlement, impaction and dispersion. Dry deposition velocities are greatly influenced by local meteorological conditions (Wesely

and Hicks 2000).

Particles $<0.01 \mu\text{m}$ are subject to brownian motion and consequently coagulate. The largest particles are removed from the atmosphere because of their relatively high sedimentation velocity. While particle of $0.1\text{-}1\mu\text{m}$ are effectively removed only by wet deposition (snow, rain etc.). Therefore residence time of particles of $0.1\text{-}1\mu\text{m}$ are long and they can be transported over thousands of kilometer (Table 5.1). For example, it is found that elevated levels of PM10 during an air pollution episode on 8th to 11th march 1996 in England is mainly due to trajectories that came directly from Germany (Malcom et al 2000). During transport the particles changes due to different physical and chemical process such as evaporation, condensation, coagulation, and reactions of gaseous ingredients on the surface and in the volume of particles (Vano et al 1999). Dry and wet deposition mechanisms are known to pollute local, regional and global land and water resources. In Greenland ice core, Chylek et al (1995) estimated an average of black carbon concentration of $2 \mu\text{g}/\text{kg}$ predominantly contributed due to wet deposition. Cariat et al (1997) in a study of mass balance between emission and deposition of air borne contaminants has reported deposition of trace metals from point industrial sources occurring up to 200 km in Kola Peninsula, Russia.

Table 5.1 Settling velocities of particulate matter

Diameter in μm	Intrinsic speed mm/s	Settling velocity mm/s
0.01	3000	0
0.1	100	0.001
1	3	0.1
10	0.1	10
100	0.1	1000

5.2.3 Characteristics of SPM

Major components of fine particles often consist of sulfates, carbonaceous materials, nitrates, trace elements and water (Bahadori et al 1999, Gamble 1998). Next to sulfates organic substances are the second major constituents of fine particulate matter representing 26–47% (Houdt 1990). In WHO (2000) review, it was found fine particles primarily consist of nitrate, sulfate and ammonium ions, which together with elemental and organic carbon make up 70–80% of the total PM 2.5 mass.

The coarse particles that are generated mainly by mechanical crushing, grinding, or abrasion of surfaces, resuspension of soil, industrial dusts and other anthropogenic activities are primarily composed of aluminosilicates and other oxides of crustal elements in soil and fugitive dust (Bahadori et al 1999, Gamble 1998). The coarse fraction is mostly dominated by aluminum, silicon, sulfur, potassium, calcium and iron, which make up 40–50% of its mass. Components such as nitrate, sulfate and ammonium ions, elemental and organic carbon made up only 10–20% of the fraction of size between 2.5 and 10 μm (WHO 2000).

5.2.4 SPM concentrations in ambient air

Trends of particulate pollution across the world mostly European countries and USA, are available in various locations. These data indicate that PM concentrations in atmosphere are gradually declining due to improvement in emission technologies and other structural changes. Nikolaou and Papaioannou (1998) noted a decreasing trend of TSP and PM 10 during 1987-95 in all their air quality monitoring stations of Thessaloniki, Greece. The study concluded that decrease is attributed to cleaner fuel quality characteristics. Fang et al (1999) in a study of characterization of TSP, PM 2.5~10 and PM 2.5 in the rural site of

Taiwan recorded an average concentration of 0.42, 0.34 and 0.019 mg/m³ respectively. They have indicated that the major composition in TSP was PM 2.5~10 in the rural site.

Ederton et al (1997) in Mexico City found about 50% of the PM 10 mass consisted of PM 2.5. The study also disclosed that although the average 24-hour PM 10 concentration during the study period was 75 µg/m³, the 24-hour standard of 150µg/m³ was exceeded in seven samples. The maximum value reached was 542 µg/m³. Nearly half of the PM 10 was composed of fugitive dust from roadsides. In Santiago, Chile during cold months the mean PM 2.5 was 71.3 µg/m³ and ranged from 10 –156 µg/m³ exceeding the standard guide lines (Ilabaca et al 1999).

A recent analysis by Vignati et al (1999) of street measurements of particle size distributions in the range 0.2 – 20 µm revealed in general very poor correlation with street traffic, but strong dependence on relative humidity. Hering et al (1998) reported high correlation between particle concentrations and secondary gaseous pollutants such as O₃, NO_x and HCOH (r = 0.81, 0.81, 0.86 respectively) measured at the same time in a polluted air mass at Swiss plateau and southern pre-Alpine region. The results also indicated that under conditions of high air pollution and strong photochemical activity, the aerosol particles grow because of secondary heterogeneous nucleation.

5.2.5 Indian scenario

India is one of the rapidly urbanizing countries with an increasing environmental pollution. Studies reveal steady increase of population in India in both urban and rural communities over the last century (Maitra 2000). The annual growth rate of urban population in India (3.09%) is more than double of that of high-income market economies. India's population crossed one billion mark on May 11, 2000 (The Hindu

2001a). By the year 2025, the population is likely to reach 1600 million. As the population increases energy consumption and demand also follow. When world's consumption of energy grew 1% in 1997, in India it grew by 6.1%. Of the total consumption of 80.41 million tones of petroleum products during 1997-1998, transport sector consumed about 40 million tones, followed by residential and industrial (12.8 and 11.74 million tones respectively) sectors. In the case of coal, industrial sector is the major consumer (60.9 million tones/year) with 60% being utilized by coal-fired power plants (Subramanian and Verma 2000).

The rapid increase in industrialization, urbanization, vehicles and population growth obviously have deteriorated the environmental quality. Especially, air quality in Indian cities is deteriorating in a fast pace. Growing vehicle fleet with the present figure crossing 35 million, is a major air pollution source in urban areas (Bhati 2000). To monitor the air quality changes, a nation-wide programme, National Ambient Air Quality Monitoring (NAAQM) was initiated in 1984. As on March 31, 1995, the network comprised 290 stations covering over 90 towns/cities distributed over 24 States and 4 Union Territories. The network is operated through the respective State Pollution Control Boards, the National Environmental Engineering Research Institute (NEERI), Nagpur and also through the CPCB. The pollutants monitored under NAAQM are Sulphur dioxide (SO₂), Nitrogen dioxide (NO₂) and Suspended Particulate Matter (SPM) besides meteorological parameters, like wind speed and direction, temperature and humidity. Annual data on air quality parameters of various places are available in detail at CPCB web site (<http://envfor.nic.in/cpcb>). The NAAQM's published station wise report on air quality parameters such as SPM, SO₂ and NO₂ are reproduced in "The Citizens Fifth Report –Part II: Statistical database" (Agarwal et al 1999). SPM data of some important cities are reproduced here in Appendix 1. Levels of RSPM are not available in any of the

NAAQM's data until 1995. The picture of atmospheric RSPM remains largely unknown in most of the Indian cities.

According to a recent report (UNEP 2001), most of the Indian cities the mean of average values of SPM for nine years (1990 to 1998) ranged between $99 \mu\text{g}/\text{m}^3$ and $390 \mu\text{g}/\text{m}^3$ in residential areas and between $123 \mu\text{g}/\text{m}^3$ and $457 \mu\text{g}/\text{m}^3$ in industrial areas exceeding the annual average limit of suspended particulate matter (For residential areas $140 \mu\text{g}/\text{m}^3$ and for industrial areas $360 \mu\text{g}/\text{m}^3$). Except for NAAQM programme, institutional/academic research on air pollution in the country is low compared to other developed and certain developing nations. Table 5.2 provides some of the records of such air pollution research carried out at various places in India.

Table 5.2 SPM levels in Indian cities reported in research journals

City	SPM Range/Mean	Observations	Author
Shimla	$53 - 322 \mu\text{g}/\text{m}^3$	Residential areas witnessed high SPM in spite of no notable industrial activity	Gupta and Vidya (1994)
Mumbai	$180-270 \mu\text{g}/\text{m}^3$ (1981 to 1990)	Annual emissions of TSP and PM 10 were 32000 and 16000 tones respectively	Shah and Nagpal (1997)
Calcutta	$982-1181 \mu\text{g}/\text{m}^3$ (1993-1994)	Higher SPM values, high benzene values	Samanta et al (1998)
Chennai	$163-1835 \mu\text{g}/\text{m}^3$	Urban areas with highest SPM values followed by industrial and residential areas	Mohan and Muthukrishnan (1996)
Bangalore	$77 - 787 \mu\text{g}/\text{m}^3$	SPM levels high at traffic junctions. Physical obstacles and topographical features minimized dispersal of SPM.	Wilson (1998)
Pune	$99-122 \mu\text{g}/\text{m}^3$	TSP concentrations in winter less compared to the beginning of summer	Rao et al (2001)
Lucknow	$200 \mu\text{g}/\text{m}^3$	-	Kulshreshtha (2000)
Mysore	$79.5- 266 \mu\text{g}/\text{m}^3$	-	Hosamani and Doddamani (1998)

Indore	285– 465 $\mu\text{g}/\text{m}^3$	-	Joshi and Mishra (1998)
Kakinada	81–324 $\mu\text{g}/\text{m}^3$	-	Rao et al (1999)
Mudumalai Forest	47.4 – 55.6 $\mu\text{g}/\text{m}^3$	Values within the prescribed limits of National Ambient Air Quality Standards for sensitive areas	Azeez et al (1997)
Udagaman dalam	22 – 96 $\mu\text{g}/\text{m}^3$ of RSPM	RSPM values higher in commercial area where traffic flow is high	Azeez et al (2000)
Suburban and Rural Coimbatore	24 – 90 $\mu\text{g}/\text{m}^3$ of RSPM	Higher RSPM values in industrial areas	Azeez et al (1999)

5.2.6 Coimbatore scenario

The present study area, Coimbatore is not an exception to the problem of environmental pollution (Mohanraj et al 2000, Mercy et al in press). The industrial growth as discussed earlier in chapter 2 has consequently promoted population growth, vehicular increase, garbage generation, sewage etc that are common sources of pollution. Industrial sources for example, The ACC, a cement making industry located 14 kms away from Coimbatore may be a major source that emits suspended particulate matter (SPM) into the atmosphere from its various operations (Umamaheswari et al 1997). SPM at different locations at the industry varied between 115 ± 9.2 to 64 ± 4.57 $\mu\text{g}/\text{m}^3$. Foundries and other alloy making industries present in and around Coimbatore release SPM and various gases into the atmosphere. The conventional founding process using cupolas, widely known for air pollution, are present in large numbers, in the city and industrial estates of Coimbatore. Even advanced alloy making process using electric induction furnace produce notable levels of SPM (Azeez et al in press). In cupolas, the particulate emissions and the metal fumes are manifold compared to induction furnace. A recent short-term study by Meenambal and Akil (2000) reported that levels of SPM at selected sites in Coimbatore city exceeding the standards set by Central Pollution Control Board (CPCB). Coimbatore is one among the regions monitored for air quality under National Ambient Air Quality

Monitoring (NAAQM) program. However the programme do not include Respirable Suspended Particulate Matter (RSPM) in the city.

5.3 Methodology

In the present study, Respirable Dust Sampler (Model. APM 451, fabricated by Envirotech, New Delhi - Plate 5) was installed at various sampling stations mentioned in the Chapter-2 and monthly air samples were collected at each station during March 1999 to February 2001. The respirable dust sampler is a high volume sampler with a cyclone attachment, which fractionates the dust into respirable and non-respirable fractions. The respirable fraction (RSPM or PM 10) of the suspended particulate matter is collected on a preweighed Whatman glass microfibre filter paper (GF/A 20.3 x 25.4 cm). SPM bigger than 10-microns (NRSPM) are collected in a separate sampling bottle. The sampler was run for 24 hours at an airflow rate of 0.9 to 1.2 m³/min.

Prior to sampling each filter paper was exposed to strong light source and inspected for pinholes, particles and other imperfections. The filter papers were pre-weighed in an electronic balance and marked for identification. The sampling procedure, instrument preparation and operation strategies were adopted as per IS: 5182 (Part iv 1973), NEERI (1985), Shannigrahi et al (1997), and operation manual of APM 451. The PM 10 collected over the GF filter paper and the NRSPM collected in the sampling bottle after 24 hrs sampling were weighed using an electronic weighing balance.

To find out the influence of local meteorological parameters on SPM characteristics, average meteorological data of air sampling day and a day prior and after to it was considered for all analysis.

5.4 Results

The overall scenario of RSPM level in all sampling stations during the study period (1999-2001) is shown in Figure 5.1. The study showed that RSPM concentration ranged between 30-149 $\mu\text{g}/\text{m}^3$ with an average of $71.3 \pm 22.26 \mu\text{g}/\text{m}^3$, while NRSPM ranged between 24.4 – 460 $\mu\text{g}/\text{m}^3$ averaging $110.8 \pm 69.15 \mu\text{g}/\text{m}^3$.

ANOVA of RSPM values showed highly significant variation among the stations (Table 5.3). Similar analysis for each station between the two study years (1999 – 2000 and 2000 – 2001) did not yield any significant variation. Results of correlation analysis to find out the relation between concentrations of RSPM and NRSPM and the local meteorological factors is given in Table 5.4

Table 5.3 ANOVA of RSPM among stations

RSPM	df	F	P<
Between Stations	5	11.93	0.000
Between 1999-2000 and 2000- 01	138	.708	.401

Table 5.4 Pearson's correlation co-efficient between SPM and meteorological factors

Parameters	RSPM	NRSPM
RSPM	1	
NRSPM	-0.003	1
Maximum Temperature (07.22 Hrs)	-0.098	0.18*
Minimum Temperature (07.22 Hrs)	-0.375**	0.183*
Relative Humidity (07.22 Hrs)	0.141	-0.112
Relative Humidity (14.22 Hrs)	-0.133	-0.125
Evaporation (mm)	-0.228**	0.27**
Wind Speed (km/hr)	-0.272**	0.275**
Rain Fall (mm)	-0.0239	-0.126
Solar Radiation ($\text{cal}/\text{cm}^2/\text{day}$)	-0.056	-0.015
Sunshine Hours	0.117	0.070

** P< 0.01, * P< 0.05

5.4.1 Station A (State Bank of India Road –Urban and Commercial Mixed)

During 1999–2001, Station A recorded an average of $84.24 \pm 7.98 \mu\text{g}/\text{m}^3$ of RSPM and $93.6 \pm 14.09 \mu\text{g}/\text{m}^3$ NRSPM (Figure 5.2). Within the study period June 1999 recorded highest value of RSPM ($120.5 \mu\text{g}/\text{m}^3$). If annual average for RSPM is considered, period from March 1999 – February 2000 (I year of the study) recorded higher average concentration ($94.1 \mu\text{g}/\text{m}^3$) than the second half of the study period, March 2000 – February 2001 ($74.4 \mu\text{g}/\text{m}^3$). Among the meteorological parameters only wind speed correlated positively with NRSPM ($r = 0.5$, $p < 0.05$, Figure 5.11).

5.4.2 Station B (Gandhipuram – Urban and Commercial Mixed)

Station B, located in the commercial hub of Coimbatore showed values of SPM similar to that of station A located about 4 Km away. As mentioned elsewhere, care was taken to keep the sampling station away from bus terminuses to avoid sampling bias from direct source. During the study period the RSPM and NRSPM values were in the range of 50 – $118.7 \mu\text{g}/\text{m}^3$ and 44.7 - $187.6 \mu\text{g}/\text{m}^3$ respectively (Figure 5.3). The mean values of RSPM and NRSPM were $84.4 \pm 16.4 \mu\text{g}/\text{m}^3$ and $122 \pm 39 \mu\text{g}/\text{m}^3$ respectively. Temperature (Minimum) had significant negative correlation with RSPM ($r = -0.58$, $p < 0.05$, Figure 5.12).

5.4.3 Station C (Saibabcolony - Urban and Residential)

Sampling station C is predominantly a residential area within the city. It recorded an average of $59.7 \pm 13.1 \mu\text{g}/\text{m}^3$ and $119.45 \pm 101.4 \mu\text{g}/\text{m}^3$ of RSPM and NRSPM respectively during the study period (Figure 5.4).

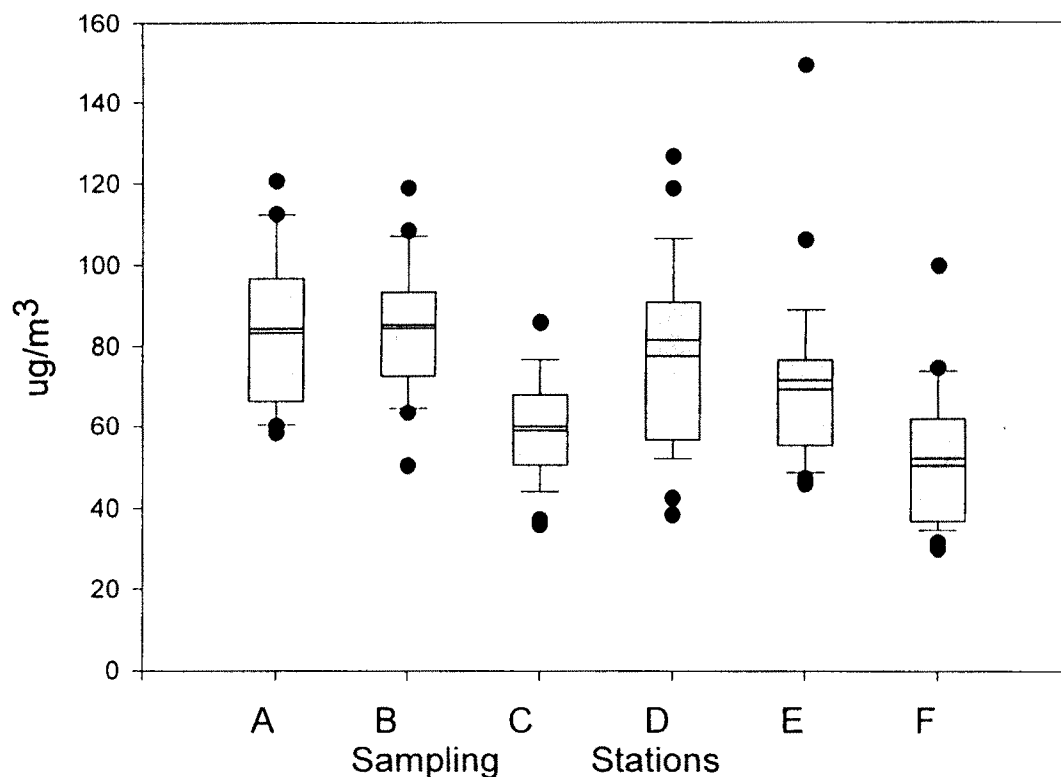


Figure 5.1. Representing statistical values of RSPM at each station during the whole study period. The boundary of the box closest to zero indicates the 25th percentile, a line within the box marks the median and mean, and the boundary of the box farthest from zero indicates the 75th percentile. Whiskers (error bars) above and below the box indicate the 90th and 10th percentiles mean and outlying points. Round dots closest and farthest from zero indicate the minimum and maximum values respectively.

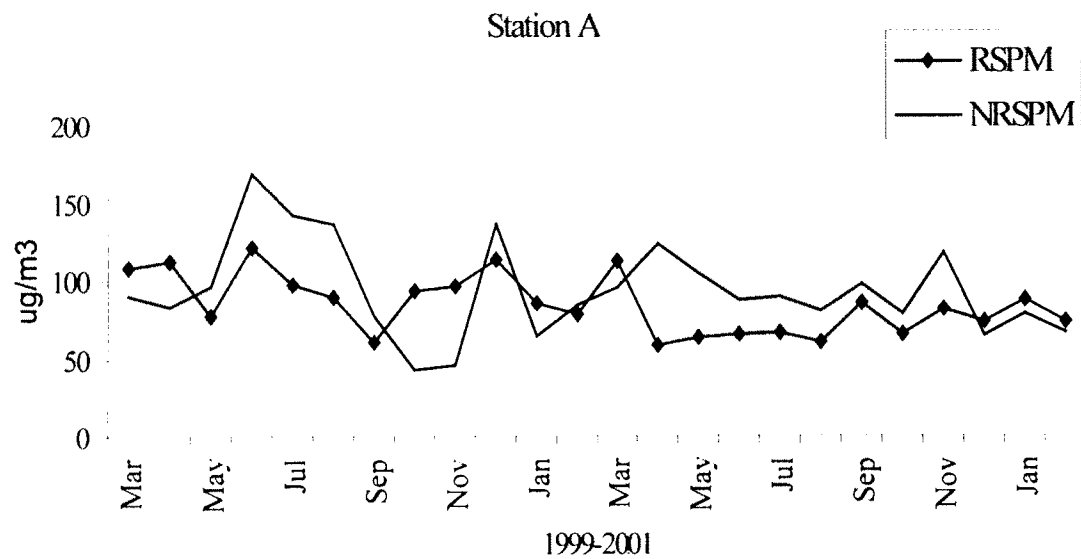


Figure 5.2 Levels of RSPM and NRSPM at station A (SBI Road)

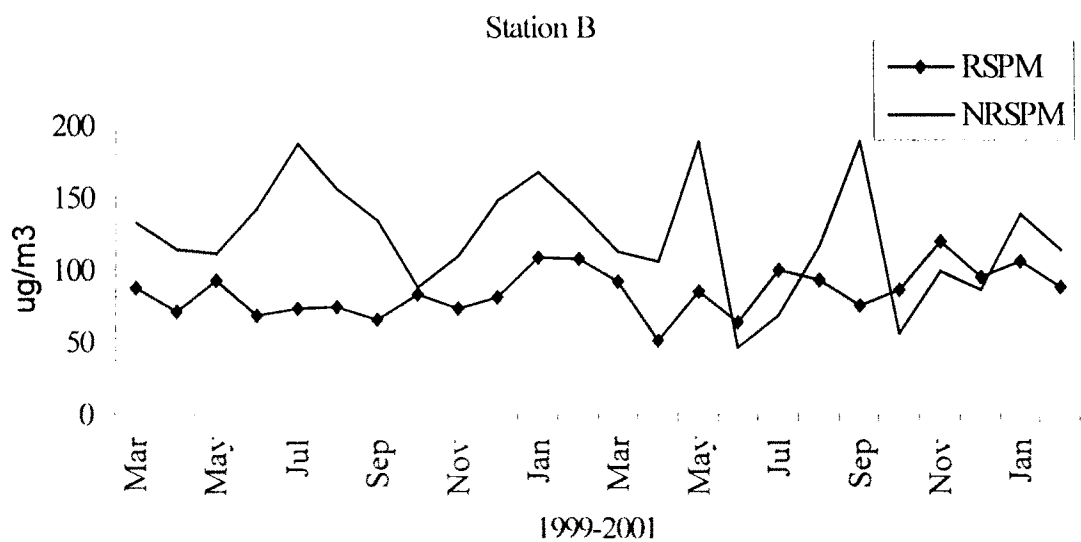


Figure 5.3 Levels of RSPM and NRSPM at station B (Gandhipuram)

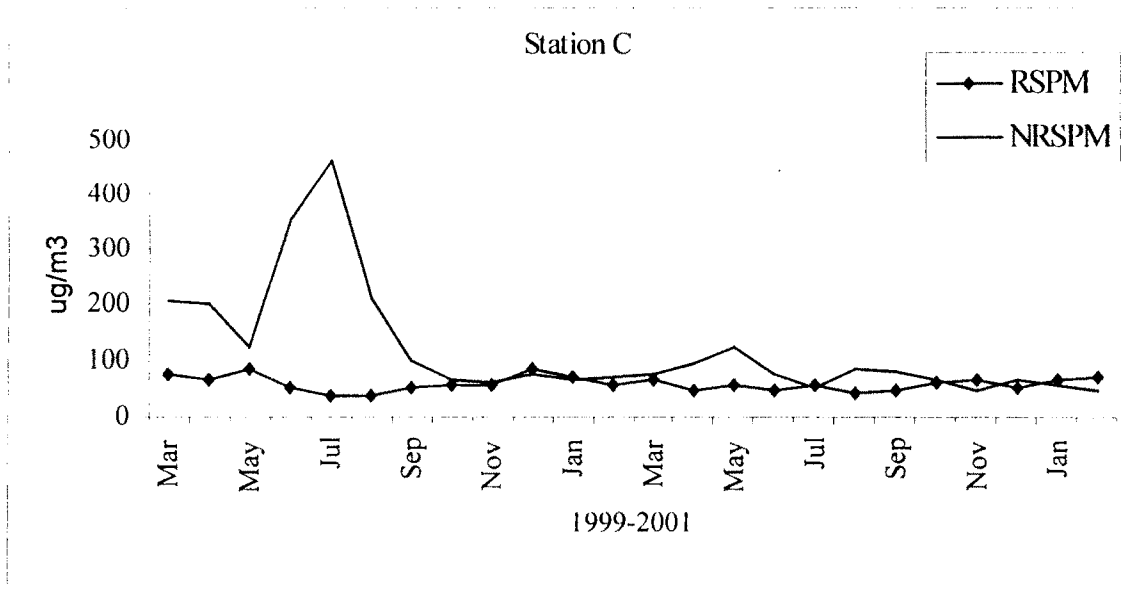


Figure 5.4 Levels of RSPM and NRSPM at station C (Saibabacolony)

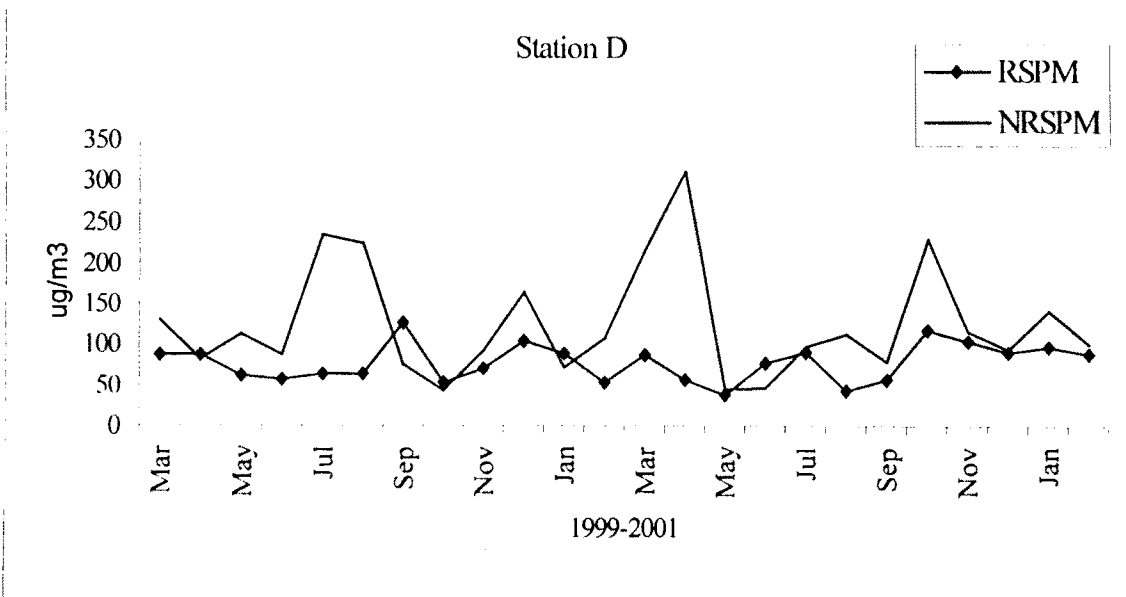


Figure 5.5 Levels of RSPM and NRSPM at station D (SIDCO)

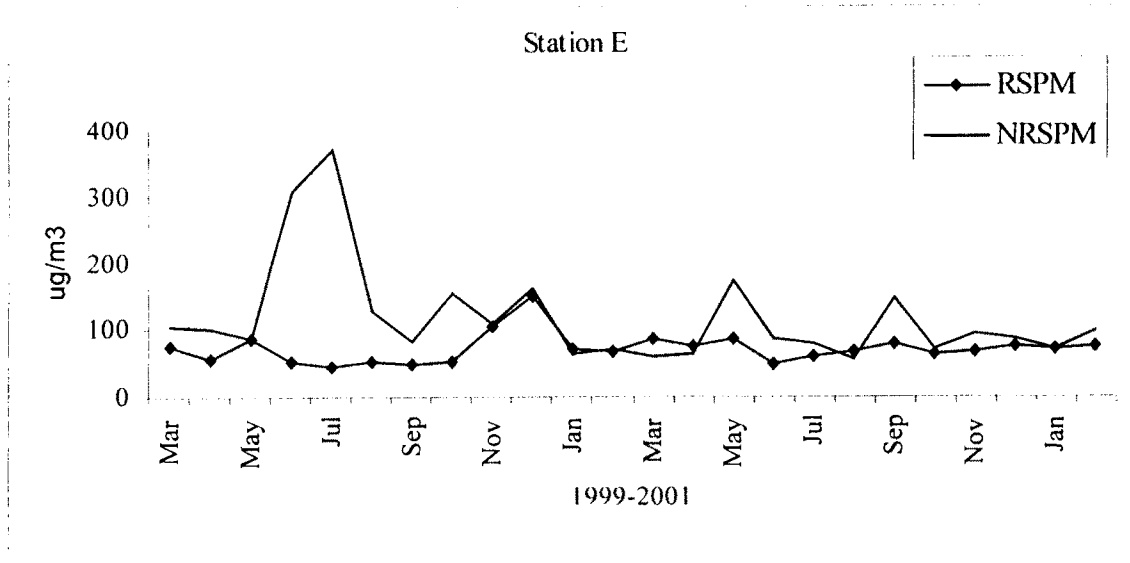


Figure 5.6 Levels of RSPM and NRSPM at station E (Peelamedu)

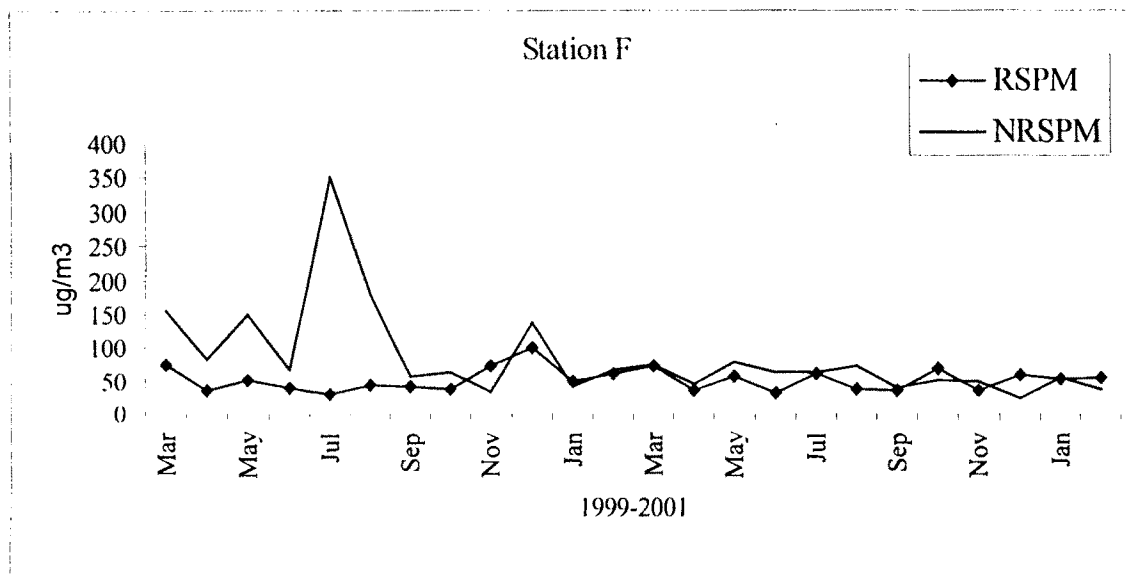


Figure 5.7 Levels of RSPM and NRSPM at station F (Kuniamuthur)

5.4.4 Station D (SIDCO - Industrial and Suburban)

An average of $77.37 \pm 23.6 \mu\text{g}/\text{m}^3$ and $123.6 \pm 72.24 \mu\text{g}/\text{m}^3$ of RSPM and NRSPM (Figure 5.5) were recorded respectively in SIDCO. No correlation was found between particulate matter and meteorological parameters.

5.4.5 Station E (Peelamedu – Suburban and Educational Institution)

The station recorded an average of $71.3 \pm 22.07 \mu\text{g}/\text{m}^3$ and $116.6 \pm 76.05 \mu\text{g}/\text{m}^3$ of RSPM and NRSPM respectively (Figure 5.6). The highest values of RSPM ($149 \mu\text{g}/\text{m}^3$) and NRSPM ($305 \mu\text{g}/\text{m}^3$) were recorded during the period, March 1999 to February 2000. Significant negative correlation was observed between RSPM values and meteorological factors such as minimum temperature and wind speed (Table 5.5).

Table 5.5 Pearson's correlation co-efficient between SPM in station E and meteorological factors

Parameters	RSPM	NRSPM
RSPM	1	
NRSPM	-0.14454	1
Maximum Temperature	-0.26916	0.138006
Minimum Temperature	-0.44*	0.30021
Wind speed (km/hr)	-0.43*	0.196235
** P < 0.01, * P < 0.05		

5.4.6 Station F (Kuniamuthur – Suburban and Rural Mixed)

An average of $51.73 \pm 17.46 \mu\text{g}/\text{m}^3$ of RSPM and $84.82 \pm 69.7 \mu\text{g}/\text{m}^3$ of NRSPM was recorded during the study period at station F (Figure 5.7), which is basically dominated by agriculture, residential and barren land. Highest and lowest RSPM values of $74.3 \mu\text{g}/\text{m}^3$ and $30 \mu\text{g}/\text{m}^3$ were recorded during March 1999 and July 1999 respectively. Relation between meteorological parameters and RSPM values of station F is given in Table 5.6.

Table 5.6 Pearson's correlation co-efficient among SPM at station F and meteorological factors

Parameters	RSPM	NRSPM
RSPM	1	
NRSPM	-0.07	1
Maximum Temperature (07.22 hrs)	-0.12	0.21
Minimum Temperature (07.22 hrs)	-0.64**	0.10
Relative Humidity (07.22 hrs)	0.25	-0.19
Relative Humidity (14.22 hrs)	-0.16	-0.26
Evaporation (mm)	-0.44*	0.36
Wind speed (km/hr)	-0.49*	0.38
Rain Fall (mm)	0.103	-0.17
Solar Radiation	-0.164	-0.07
Sunshine Hours	0.126	0.11
** P< 0.01, * P< 0.05		

5.5 Discussion

Overall RSPM concentrations in Coimbatore vary in the order of Urban and Commercial mixed > Suburban-Highway > Industrial > Urban-Residential > Suburban and Rural (Figure 5.1). It clearly shows that sampling stations in urban areas, especially those with frequent vehicular traffic and traffic congestion (station A and B), witnessed comparatively high RSPM values. Station E, although present in suburban environment but lying close to highway, had RSPM concentrations next to urban sampling stations A and B suggesting that traffic as a major contributor to RSPM. ANOVA of RSPM (Table 5.2) reveals significant change in type or quantity of background air pollution sources among the stations.

According to the NAAQM's report, in Coimbatore air pollution is not severe, however the city is classified as moderately polluted area. An average $40.7 \mu\text{g}/\text{m}^3$, $65.7 \mu\text{g}/\text{m}^3$ and $42.5 \mu\text{g}/\text{m}^3$ of total SPM were recorded during NAAQM survey in 1993, 1995 and 1997

respectively (Agarwal and Narain 1999). In the present study the total SPM (RSPM+NRSPM) ranged between 136.5 – 206.5 $\mu\text{g}/\text{m}^3$ indicating sharp increase in SPM levels. The hike observed in SPM levels in Coimbatore may be probably attributed to the rapid increase in vehicular population (Chapter 4, Table 4.12) and traffic congestion. No major air polluting industries were newly established during the period of NAAQM's report and current study suggesting that vehicles could be the major source for increasing air pollution. A notable percentage of vehicles plying in Coimbatore do not comply with the traffic norms (Chapter 4, Figure 4.1).

Apart from vehicular emission, burning of garbage and backyard wastes in Coimbatore contributes significantly to the SPM levels. Coimbatore city alone generates 650-700 tonnes of garbage every day (The Hindu 2001b). The huge pile of garbage containing plastics and other toxic materials dumped at certain locations in the city smolder releasing huge amount of smoke (Plate 6 and Plate 7). According to a recent estimate (Indira Gandhi Institute for Development Research 2000), burning a tonne of garbage produces 0.098 tonnes of SPM, 0.072 tonnes of SO_2 , 0.136 tonnes of volatile hydrocarbons, 0.018 NO_2 and 0.38 tonnes of CO.

Meteorological parameters are found to influence RSPM and NRSPM values (Table 5.4). Wind speed is negatively correlated with RSPM (Figure 5.8), while it had a positive correlation with NRSPM (Figure 5.9). Such a relationship indicates that higher wind speed has high dilution effect on fine particles especially PM 10. At the same time a strong wind is likely to resuspend the dust particles from the soil contributing to higher NRSPM concentrations. Temperature (minimum) also had a negative correlation with RSPM values (Figure 5.10) indicating the winter seasons having higher RSPM. Elevated SPM values in winter are one of the common phenomena ever since air pollution is

being studied. Several air pollution tragedies, even the notorious London smog catastrophes that resulted in heavy mortality occurred in winter. Harrison et al (1997) obtained negative correlation between PM 2.5 and wind speed and positive correlation between coarse PM and wind speed. Miranda et al (2000) observed dramatically high concentrations of particulate matter in winter and spring in Mexico and also found that there is a transport of pollutants from west towards the sampling site during the morning, while in the night transport corresponds to soil derived dust from north.

In station A (urban), first year of the study period (March 1999 – February 2000) recorded higher average concentration ($94.1 \mu\text{g}/\text{m}^3$) than the second year (Mar 2000- Feb 2000, $74.4 \mu\text{g}/\text{m}^3$, Figure 5.2). Such reduction in RSPM value during the second year of study probably may be attributable to the improvement in road network around the station coupled with advent of emission norms. Lack of seasonal inclination in RSPM values in the station A indicates to some local sources such as railway diesel engines or other uncontrolled smoke releasing activity such as garbage burning in close vicinity of the sampling station influencing the ambient RSPM concentration. Among the meteorological parameters, wind speed had positive correlation with NRSPM values ($r = 0.5$, $p < 0.05$, Figure 5.11). Overall annual average RSPM in Station A exceeded the permissible limit of $60 \mu\text{g}/\text{m}^3$ set by CPCB, India (CPCB 2000a, Appendix 2).

In Station B (urban), annual average RSPM values exceeded the permissible limit of $60 \mu\text{g}/\text{m}^3$ set by CPCB (Appendix 2). Although Station B lies in urban area, unlike Station A no significant correlation was obtained between the RSPM and NRSPM values probably indicating different sources for each. Higher values of RSPM were obtained in November – January (post monsoon season and winter) during both the years of study.

The minimum temperature had negative correlation on the RSPM Values ($r = -0.58$, $p < 0.01$, Figure 5.12).

In station C, although annual average of RSPM values did not exceed the standard limit of CPCB, during winter the values are found exceeding $60 \mu\text{g}/\text{m}^3$. However, during the study period the RSPM values had not exceeded the 24-hour average of $100 \mu\text{g}/\text{m}^3$. In the case of NRSPM, comparatively very high standard deviation was observed in Station C unlike in other stations. Such variation was due to distinctly higher NRSPM values during March 1999 – August 1999 (Figure 5.4). During that period entire roads in and around the sampling station (1 km surroundings) were excavated for constructing drainage and left incomplete for about six months. It is apparent that high NRSPM values were contributed by fugitive dust from agitated soil as vehicles ply on the roads. Wind speed also had significant positive correlation in enhancing the NRSPM values ($r = 0.47$, $P < 0.01$, Figure 5.13). Similar to most other sampling stations temperature (minimum) and wind speed was major impacting factors for RSPM values. As temperature (minimum) decreases a higher RSPM values were observed. In other words winter recorded higher RSPM ($r = -0.47$, $P < 0.05$).

In station D (Industrial area), the annual average of RSPM was within the CPCB standards for industrial area (Appendix 2). No significant relationship was obtained between RSPM, NRSPM and any meteorological parameters. Many industries in SIDCO operate inconsistently depending on the market requirements and many other factors. Hence, the varying operation or shutdown of such industries modifies the air quality greatly in their immediate vicinity. A seasonal trend or correlation with meteorological parameters is apparently unlikely due to such varied operation of industries.

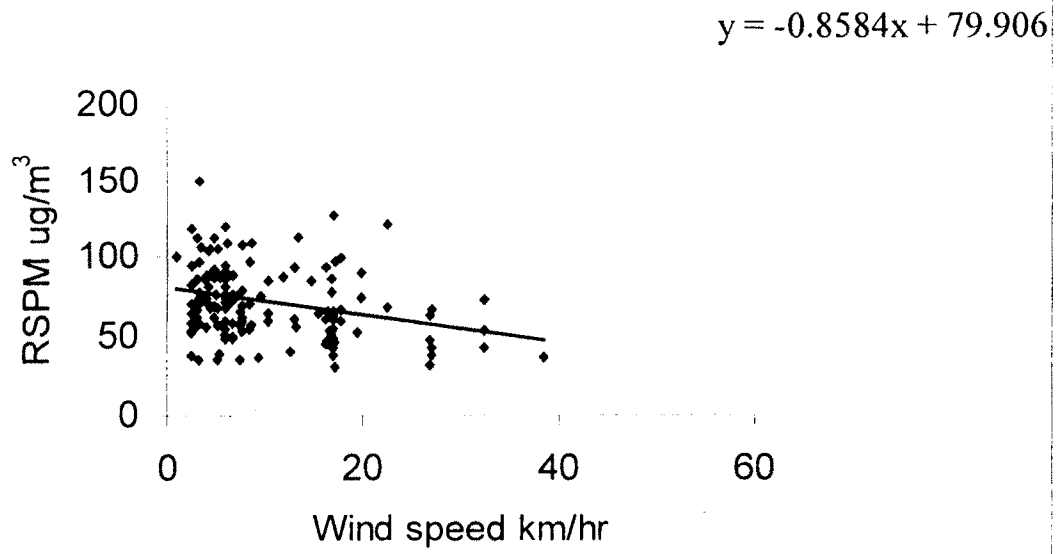


Figure 5.8 Linear regression between RSPM and wind speed

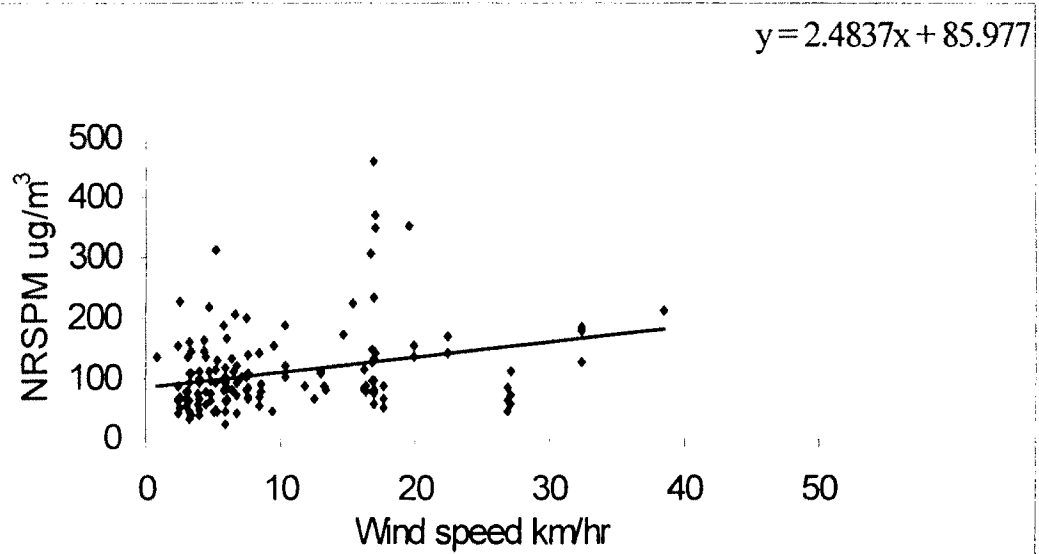


Figure 5.9 Linear regression between NRSPM and wind speed

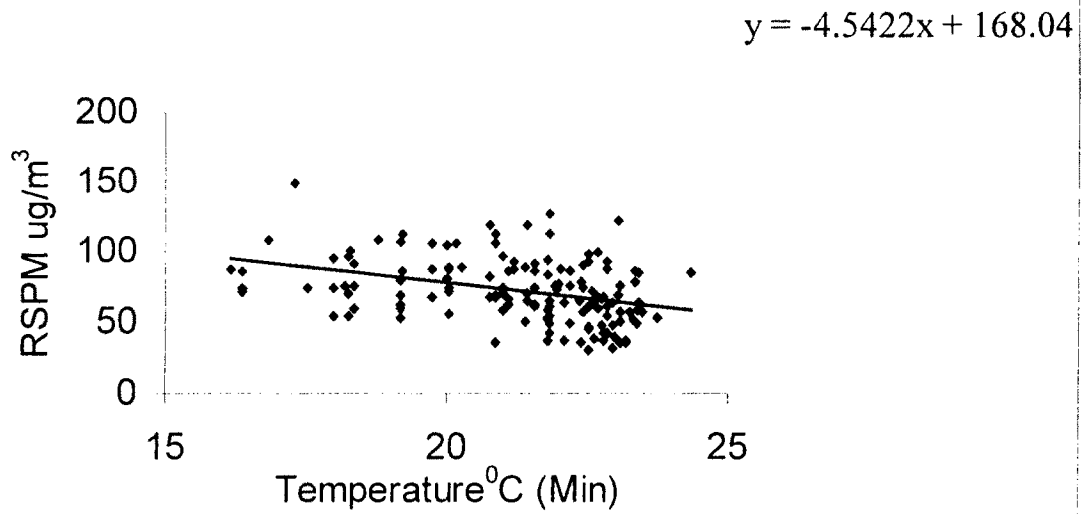


Figure 5.10 Linear regression between RSPM and temperature (minimum)

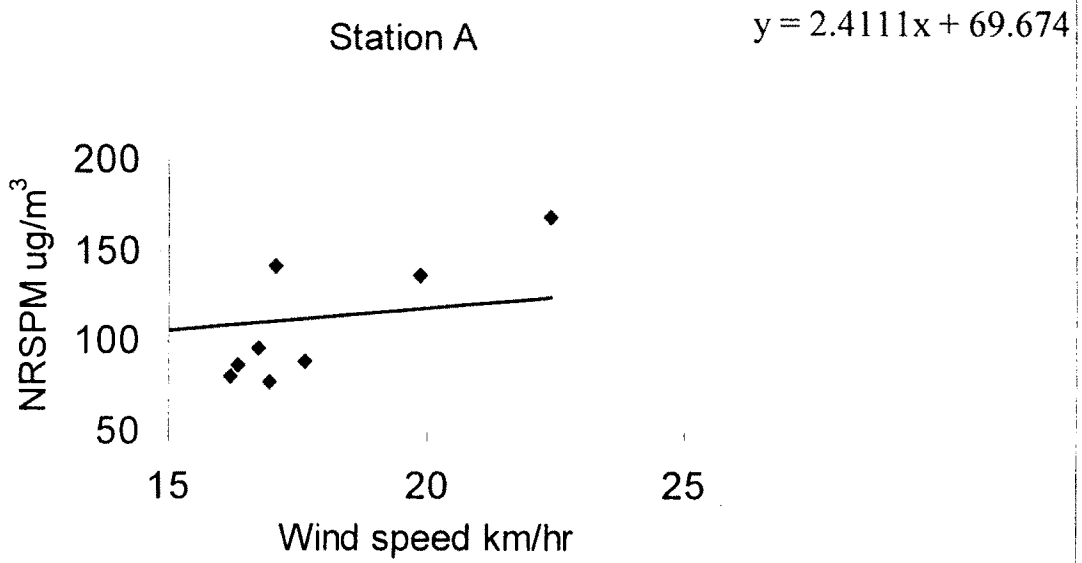


Figure 5.11 Linear regression between NRSPM (Station A) and wind speed

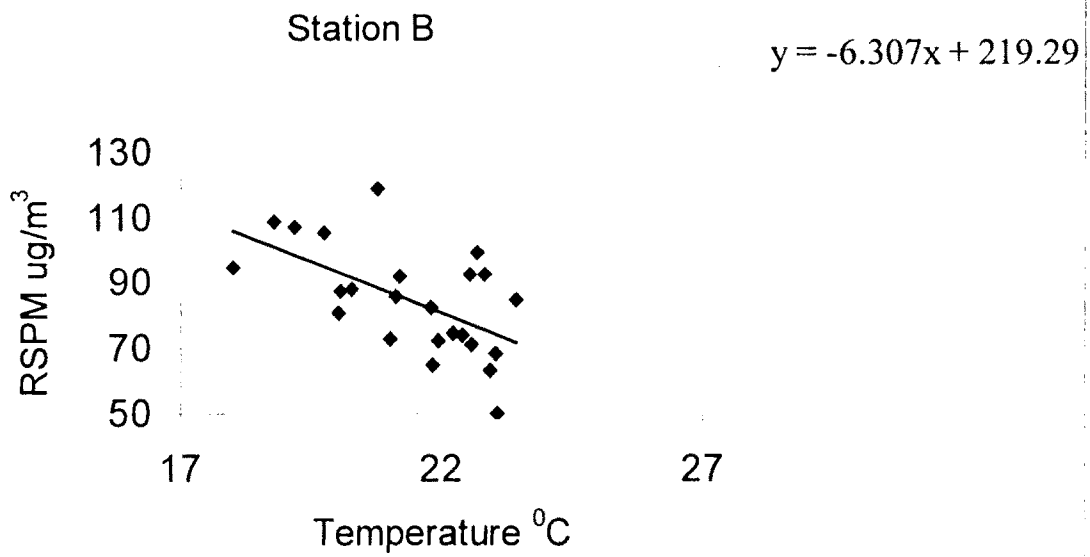


Figure 5.12 Linear regression between RSPM (Station B) and temperature (minimum)

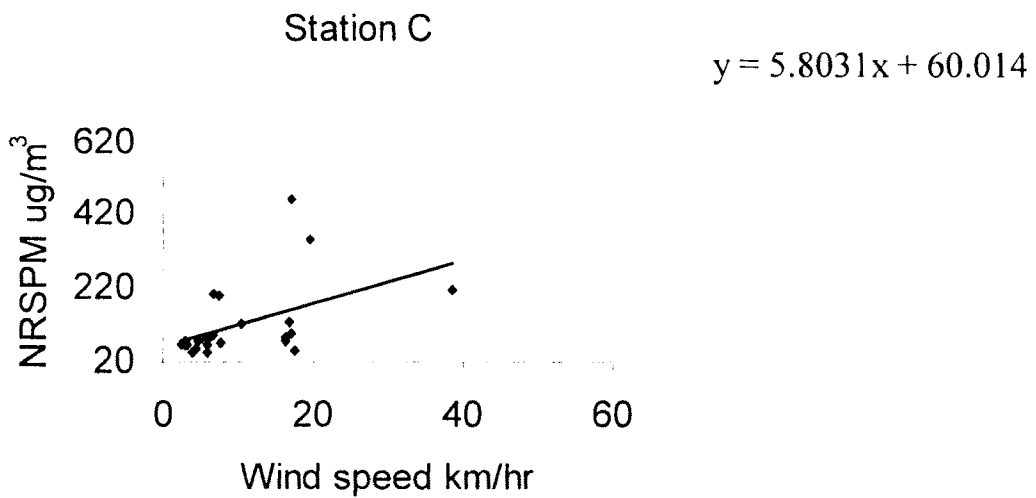


Figure 5.13 Linear regression between NRSPM (Station C) and wind speed

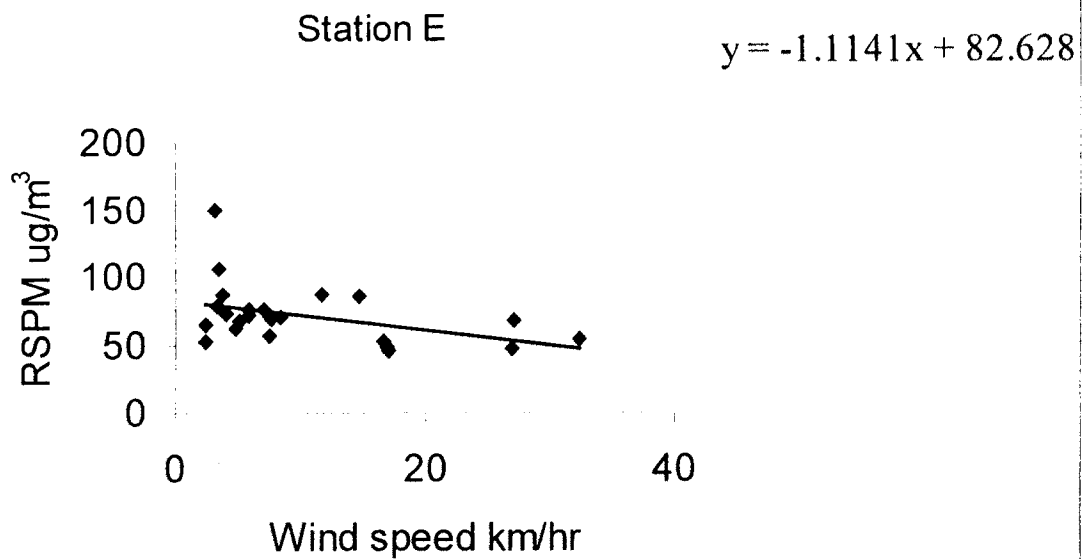


Figure 5.14 Linear regression between RSPM (Station E) and wind speed

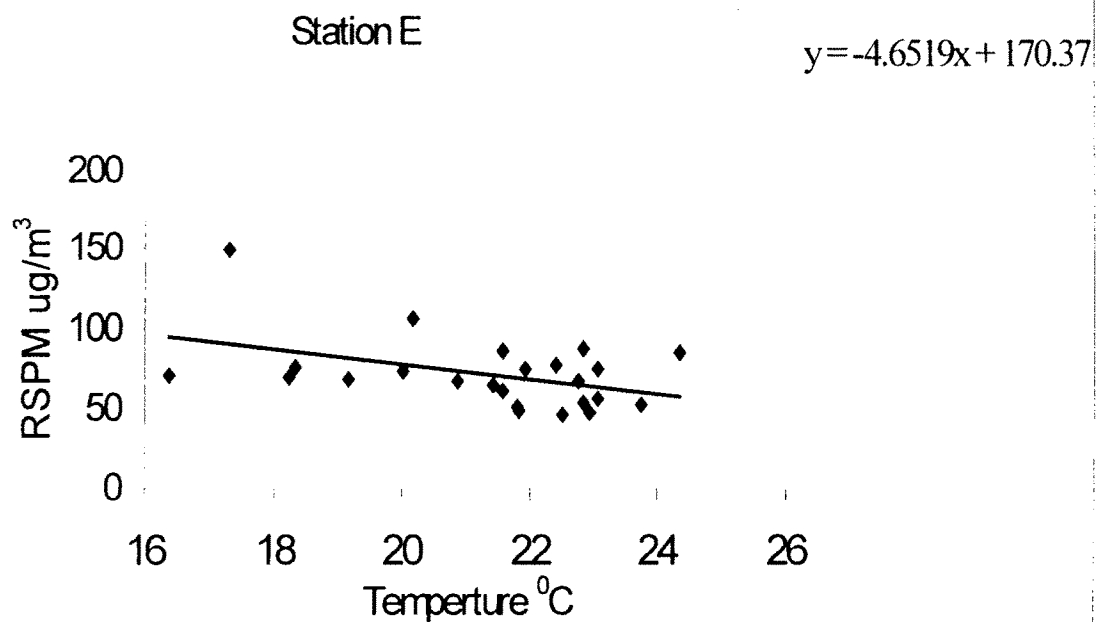


Figure 5.15 Linear regression between RSPM (Station E) and temperature (minimum)

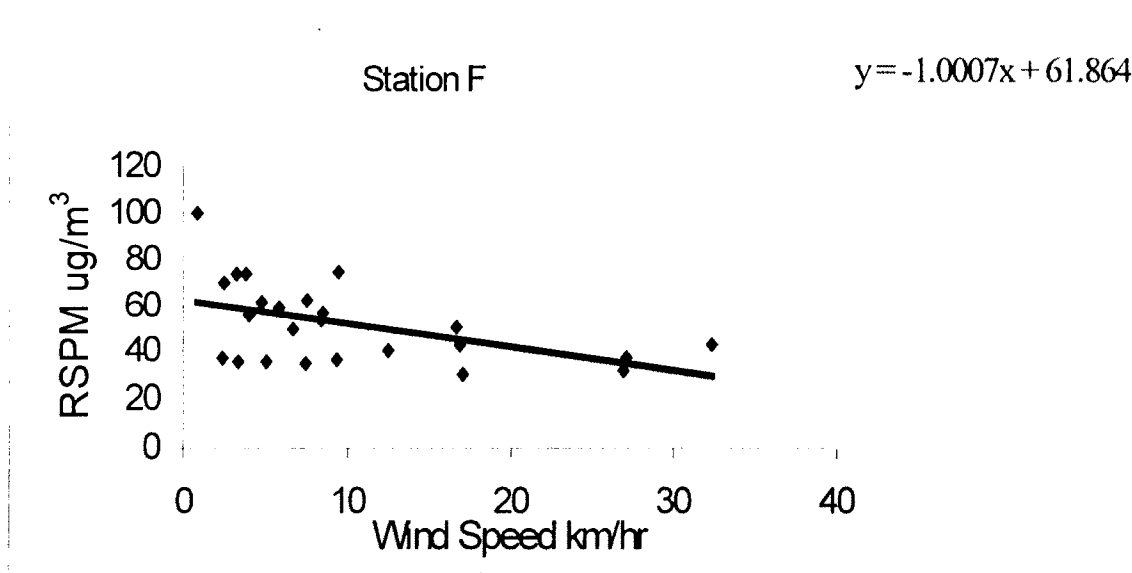


Figure 5.16 Linear regression between RSPM (Station F) and wind speed

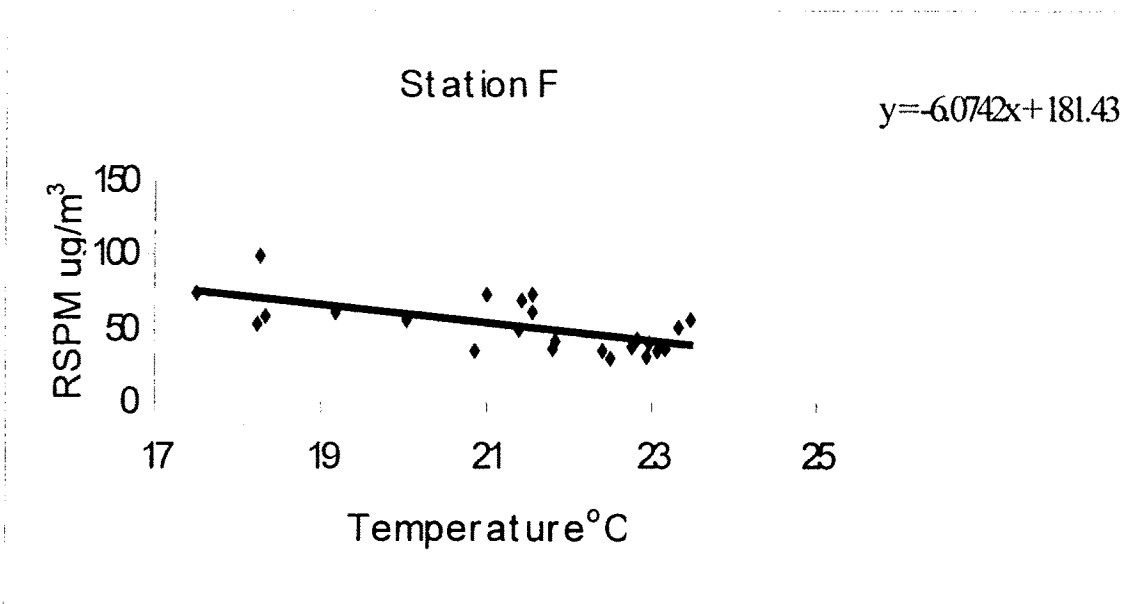


Figure 5.17 Linear regression between RSPM (Station F) and temperature (minimum)

In station E (Suburban- close to highway), annual average RSPM exceeded the permissible limit of $60 \mu\text{g}/\text{m}^3$ set by CPCB. High fluctuation was observed in RSPM values ($149 \mu\text{g}/\text{m}^3$), during December 1999 and $46.83 \mu\text{g}/\text{m}^3$ during July 1999. Since highway is the major source with no notable seasonal variation in automobile traffic, it is very likely that wind has major influence on RSPM concentrations among the seasons. RSPM concentrations were negatively correlated with temperature (minimum) and wind speed (Figure 5.14 and Figure 5.15). No other meteorological factors had significant effect on SPM at Station E.

In station F (Suburban and rural mixed), alike other sampling stations, the meteorological parameters such as temperature (minimum) and wind speed had a significant negative relationship with RSPM (Figures 5.16 and 5.17) During the period March 1999 to December 1999, NRSPM showed wide variation from 33 to $350 \mu\text{g}/\text{m}^3$ (Figure 5.15). Further observations showed it to be an effect of operation of a sawmill that emitted saw dust into the atmosphere. Since the operation of the mill stopped after December 2000, values of NRSPM fell during the later half of the study period. Annual average RSPM in station F was within the CPCB air quality standard.

5.6 Summary and Conclusion

An assessment of air borne suspended particulate matter of size below and above 10 microns were done at six sampling stations in Coimbatore using Respirable Dust Sampler during March 1999 to February 2001. RSPM concentrations among the stations ranged between $30\text{-}149 \mu\text{g}/\text{m}^3$ with an average of $71.3 \pm 22.26 \mu\text{g}/\text{m}^3$, while NRSPM ranged between $24.4 - 460 \mu\text{g}/\text{m}^3$ averaging $110.8 \pm 69.15 \mu\text{g}/\text{m}^3$.

An ANOVA in RSPM values showed highly significant variation among the stations. Except the samples of rural and industrial area, annual average of RSPM in all other urban and suburban samples, except station C (Urban-Residential) exceeded the CPCB standard of $60 \mu\text{g}/\text{m}^3$. Present study shows that SPM (RSPM+NRSPM) levels in Coimbatore have increased compared to the earlier data reported by National Ambient air quality survey. Observed hike in SPM levels in Coimbatore is probably attributed to the rapid increase in vehicular population and traffic congestion.

Meteorological parameters are found to influence RSPM and NRSPM values. Wind speed is negatively correlated with RSPM, while it had a positive correlation with NRSPM. Temperature (minimum) also had a negative correlation with RSPM values.

According to Dinda et al (2000), many studies have found an inverted U shaped relationship (Environmental Kuznets Curve – EKC) between air quality deterioration and economic growth. The explanation for such relationship was (i) use of environment as a major source of inputs and a pool for waste assimilation increases at the initial stage of economic growth, but as country grows richer, technological innovation and structural changes that take place would result in environmental protection and (ii) the status of environment quality changes from luxury to necessary. Currently developing countries have been copying air pollution control strategies adopted by developed countries (Bravo and Torres 2000). Although many studies find an EKC in developed world, situation in India is unexplored.



Plate 5 Respirable Dust Sampler (Model. APM 451, fabricated by Envirotech)

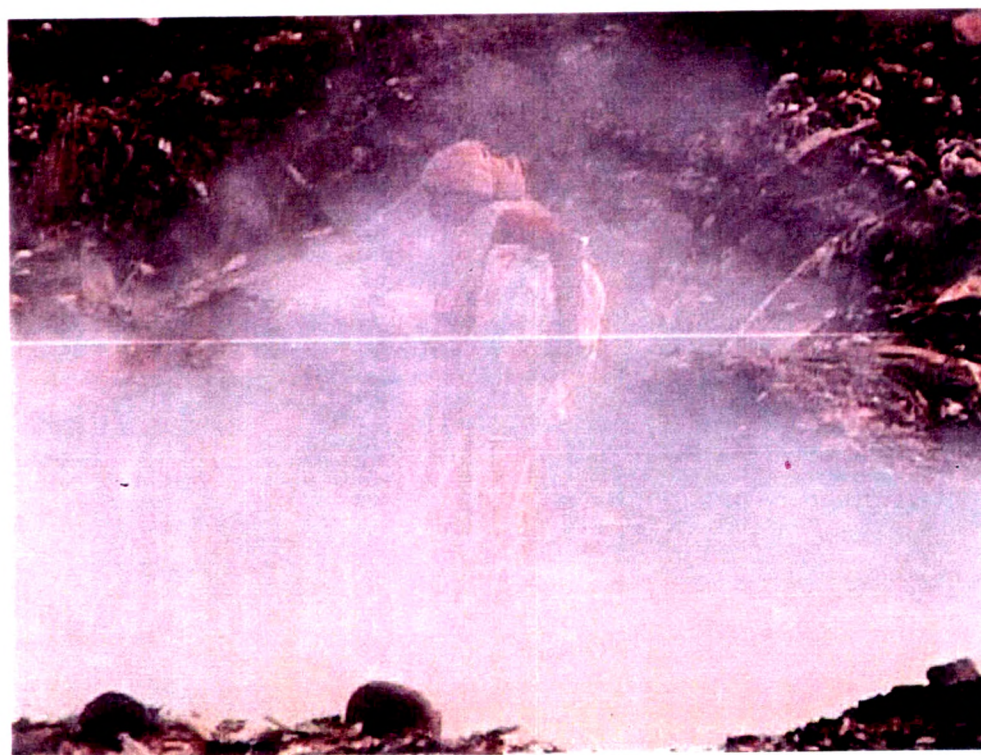


Plate 6 A scene at garbage dump site in Coimbatore

Plate 7 A rag picker in garbage dump site

CHAPTER – 6

Heavy Metals in RSPM

6.1 Introduction

About 96% of the total mass of any organism is made up of oxygen, carbon, hydrogen and nitrogen, while calcium, phosphorus, sulphur, potassium, sodium, chlorine and magnesium make up about 3.6%. The remaining 0.4% is contributed by heavy metals (Bishop 2000). Many metals are normal constituents of tissue while metals like arsenic, antimony, lead, cadmium, mercury and bismuth are known to be toxic even at low levels. It is well recognized that metals have definite influence on the biological functions affecting the normal development and growth of body tissues and their proper functioning (Fergusson 1990, Dasilva and Williams 1991).

6.2 Background

6.2.1 Sources and concentrations of heavy metals in air

Metals and their compounds, both inorganic and organic, are released to the environment as a result of a variety of human activities (<http://www.unep.org/unep/gpa/pol2a10.htm>). Main anthropogenic sources of heavy metals are various industrial sources such as present and former mining activities, foundries and smelters, and diffuse sources such as combustion, traffic, piping etc. According to Irwin (1997) major activities emitting heavy metals in the air are organic and inorganic petro-chemical processing, steel and metal foundries, motor vehicles, fertilizers, other industrial activities such as glass, cement, asbestos manufacture, textile mills and steam generation power plants. Other sources include wind transport from road dust, incineration of municipal refuse and sewage sludge. The burning of wood in fireplaces, campfires, leaf burning, and rubbish incineration also may contribute heavy metals to the air.

In Thessaloniliki, Greece, oil burning (15% - 12%), non-ferrous metal processing (10% - 8%), soil re-suspension (7% - 14%), and motor vehicle emissions (4% - 5%) were identified important sources for heavy metal concentrations in particulate matter (Samara and Kouimtzis 1994). Samara et al (1990) in their studies in Thessaloniki, Greece observed that Pb, Zn and Cu were emitted from man-made emission sources, while V, Ni and Co was derived from natural and man-made sources. Wichmann et al (2000) in a review on combustion reported that in coal combustion more than 90% of metals like Cu, Pb, Zn are found in fly ash. Most of the heavy metals in urban areas are from the vehicular exhaust that get deposited right beside the road and impart high concentrations to road run-off water. In a study conducted in Mexico using Principal Component Analysis (PCA), Miranda et al (2000) showed that the heavy metals as fine particulates were emitted from four sources namely soil, traffic-industry, Cl-Zn and Al-Cu. The study further showed that the metals in coarse particles were emitted by soil, fuel oil, industry and traffic.

Concentrations of heavy metal in air vary widely according to the background environment. At point sources and urban areas comparatively high concentrations are reported, while in remote areas free from anthropogenic sources the concentrations are generally low (Table 6.1).

Table 6.1 Heavy metal concentrations in air at various places

Metal	Concentrations in air	Location	Author
Pb	0.1– 0.3 $\mu\text{g}/\text{m}^3$	Normal range recorded in USA in 1987	Abbasi et al (1998), Krishnamurti and
	0.3 – 4.0 $\mu\text{g}/\text{m}^3$	Near point sources such as lead smelters and battery plants	

Pb	0.23 - 0.82 and 0.10 $\mu\text{g}/\text{m}^3$	In rural areas of London and of Suffolk	Viswanathan (1991), Bharma and Costa (1992)
	0.3 - 9.0 ng/m^3	In remote areas free from urban influences - Norwegian Arctic in 1983	
	775 ng/m^3	Milan and suburban areas of Italy	Gallorini et al (1998)
	120 - 7100 ng/m^3	Thessaloniki, Greece	Samara (1990)
	58 - 65 ng/m^3 (in coarse + fine fractions)	Mexico	Miranda et al (2000)
	10 - 100 ng/m^3	Southern Poland	Wrobel et al (2000)
	8.8 ng/m^3	Vingola, West Corsica	Sandroni and Mignon (1997)
	0.45 $\mu\text{g}/\text{m}^3$ in the	Village of Aznalcazar, Gudiamar valley, south west Spain	Querol et al (1999)
	6.1- 31.3 ng/m^3	Palmanyola and H. Joan, Spain	Mateu et al (1999)
	0.15 - 5.69 $\mu\text{g}/\text{m}^3$	Bangalore city, India	Wilson (1998)
Cu	5 - 50 ng/m^3	Rural areas	Abbasi et al (1998), Krishnamurti and Viswanathan (1991) Bharma and Costa (1992)
	30 - 200 ng/m^3	Urban areas	
	0.29 - 12 ng/m^3	Remote locations free from urban or industrial influences	
	0.06 ng/m^3	Pre-industrial atmospheric concentration of copper	Bharma and Costa (1992)
	45 - 603 ng/m^3	Thessaloniki, Greece	Samara (1990)
	65 in ng/m^3 (coarse + fine fractions)	Mexico	Miranda et al (2000)
	0.45 $\mu\text{g}/\text{m}^3$	Village of Aznalcazar, Gudiamar valley, south west Spain	Querol et al (1999)
	4.5 - 43 ng/m^3	Palmanyola and H. Joan Spain	Mateu et al (1999)
Cr	Below detectable - 0.6 $\mu\text{g}/\text{m}^3$	Residence time in the atmosphere is estimated to be less than 14 days.	Abbasi et al (1998), Krishnamurti and Viswanathan (1991), Bharma and Costa (1992)
	<10 ng/m^3 in rural areas, 10 - 50 ng/m^3	Industrial cities	
	70 ng/m^3 (average)	Milan and Suburban areas of Italy	Gallorini et al (1998)
	60 and 61 ng/m^3 (coarse + fine fractions)	Mexico	Miranda et al (2000)
	0 - 58.9 ng/m^3	Palmanyola and H. Joan, Spain	Mateu et al (1999)
	1 - 33.5 ng/m^3	Thessaloniki, Greece	Samara (1990)
Cd	0.1 - 5 ng/m^3	Rural areas	Abbasi et al (1998), Krishnamurti and

	2 – 15 ng/ m ³	Urban areas	Krishnamurti and Viswanathan (1991), Bharma and Costa (1992) www.cadmium.org
	15 to 150 ng/m ³	In industrialised areas	
	8 ng/m ³	Milan and suburban areas of Italy	Gallorini et al (1998)
	0.11 ng/m ³	Vingola, West Corsica	Sandroni and Migon (1997)
	0 – 0.9 ng/m ³	Mallorca, Spain	(Mateu et al 1999)
Zn	0.01 – 0.1 µg/m ³	Rural locations	Abbasi et al (1998), Krishnamurti and Viswanathan (1991), Bharma and Costa (1992)
	0.1– 0.5 µg/m ³	Urban areas	
	0.67 µg/m ³	Average concentration in US	
	85 ng/m ³	Milan and Suburban areas of Italy	Gallorini et al 1998
	61 – 466 ng/m ³	Thessaloniki, Greece	Samara (1990)
	65 in ng/m ³ (both coarse + fine fractions)	Mexico air	Miranda et al (2000)
	10 – 100 ng/m ³	Southern Poland	Wrobel et al (2000)
	0.45 ng/m ³	Village of Aznalcazar, Gudiamar valley, south west Spain	Querol et al (1999)
	0-196 ng/m ³	Palmanyola and H.Joan ,Spain	Mateu et al (1999)
Ni	0.03 µg/m ³	Average concentration in US urban air	Abbasi et al(1998), Krishnamurti and Viswanathan (1991), Bharma and Costa (1992)
	0.46 µg/m ³	Highest observed in US air	
	11.9 – 43 ng/m ³	Thessaloniki, Greece	Samara (1990)
	0 – 53.7 ng/m ³	Palmanyola and H.Joan, Spain	Mateu et al (1999)

6.2.2 Toxicity of heavy metals

Metals absorbed into the human body through inhalation eventually reach its target organ, the brain, the liver, the blood, reproductive system or any other such systems in the body (Abbasi et al 1998, Irwin 1997). The fate of metal inside the body is determined by its ability to modify these systems. Excess metals in body are excreted through urine and faeces or accumulated in various tissues. At higher concentrations metals become toxic.

Metal toxicity in organisms are greatly influenced by environmental conditions, natural and biological factors such as age, sex, species differences, stress, relationship between metals and metal-ion balances in biological system.

The inhalable fraction (0-9 μ m) of particulate matter contains high concentrations of elements of toxicological interest (Rizzio et al 1999). About 75-90% of the metals such as Cu, Cd, Ni, Zn, Pb are found in the PM 10 fraction. Among the PM10 fraction, alveolar fraction (0-1.1) contained 50-70% of these metals followed by bronchial fraction (1.1-4.6) and tracheo-pharyngeal fraction (4.6-9 μ m).

Among the heavy metals, lead is a ubiquitous environmental toxin that induces a broad range of physiological, biochemical and behavioral dysfunction (Flora 2002). It is known to affect structure and function of various organs and tissues. Its effects on haematopoietic system include inhibition of hemoglobin synthesis resulting in anemia and shortened life spans of circulating erythrocytes. Long-term exposure to lead may give rise to irreversible functional and renal changes. Encephalopathy is an effect of lead on central nervous system characterized clinically by ataxia, coma, and convulsions. It is also known to cause immunological and reproductive effects such as sterility, abortion, still births and neonatal deaths. Bone, is the largest depository of the body burden lead. It is recognized that lead may affect bone metabolism and directly or indirectly alter bone cell function. Renal disease has long been associated with lead poisoning (Logham-Adham 1997). Acute exposure to high concentrations of lead results in proximal tubular dysfunction with characteristic histologic features manifested by glycosuria and aminoaciduria. Chronic exposure has also been linked to renal dysfunction characterized by glomerular and tubulointerstitial changes resulting in chronic renal failure, hypertension, hyperuricemia and gout. Lead is also known to cause several other

cytogenetic effects and neurological effects (www.environment.gov.au). Although lead is classified as carcinogen in experimental animals, National Health and Nutrition Examination Survey (US), concluded that blood lead levels do not appear to have increased risk of cancer mortality (Jemal et al 2002).

Excess cadmium exposure produces adverse health effects in human beings. About 30 - 64% of inhaled cadmium is absorbed by the body, depending upon the chemical form, solubility and particle size of the material inhaled. Inhalation of cadmium leads to several disorders (Irwin 1997) as mentioned below; i) Shortness of breath, chest pain, cough with foamy or bloody sputum. ii) Pulmonary rales and related physical signs. iii) Weakness, leg pains. iv) An asphyxial death from intense pulmonary edema. v) Gradual resolution of pulmonary edema (over a period of a few days) and development of fever, with persistence of cough, chest pain and dyspnea for one or more weeks. vi) Late kidney and/or liver damage has followed respiratory exposures in industry. vii) Further inhalation and overexposure results in irreversible renal tubular damage, which may progress into complete Fanconi syndrome with decreased tubular reabsorption of proteins, glucose, amino acids, calcium, phosphorus, and with decreased ability to acidify and concentrate the urine. More recently, the possible role of cadmium in human carcinogenesis has also been studied, but the data is limited. A two-fold excess risk of lung cancer was observed in cadmium smelter workers (www.cadmium.org).

Nickel is listed by the Environmental Protection Agency (USA) as one of the 129 priority pollutants. It is considered to be one of the 14 most noxious heavy metals (Irwin 1997). Nickel is listed among the 25 hazardous substances thought to pose the most significant potential threat to human health. Nickel carbonyl is among the most toxic nickel compounds. Inhalation of nickel is known to cause several disorders (Bharma and Costa

1992), such as dermatosis including contact and atopic dermatosis and asthma, hypertropic rhinitis. Nasal sinusitis has been associated with inhalation of Ni containing mists. These conditions are frequently accompanied by nasal polyposis and perforation of nasal septum and pulmonary irritations, exposure to nickel carbonyl produces nausea, vertigo, headaches, dyspnea and chest pain, and interstitial pneumonitis accompanied by hemorrhage or pulmonary edema after 4-13hrs exposure.

Toxicity of Chromium is largely associated with hexavalent form. Symptoms of acute chromium exposure include allergic contact dermatitis, skin ulcers, nasal ulcers and nasal membrane inflammation. Chronic exposure results in nasal septum perforations, rhinitis, liver damage, pulmonary congestion, edema, and nephritis (Bharma and Costa 1992). Hexavalent and trivalent chromium possesses carcinogenic properties (Hueper and Payne 1962). An inhalation study with rats showed increase in incidence of lung cancers after long-term exposure to low levels of Cr ($100 \mu\text{g}/\text{m}^3$). Excess lung cancer incidents have been reported in workers of chromate-producing industry (Bharma and Costa 1992). Chromium exposure is also associated with genotoxicity and mutagenicity.

Zinc is considered to have low toxicity for humans, although in concentrations beyond certain limits it can be toxic. Symptoms of zinc toxicity include vomiting, dehydration, stomach pain, nausea, lethargy, dizziness and muscle incoordination (Abbasi et al 1998, Irwin 1997).

6.2.3 Indian scenario

Gajghate and Hazan (1997) found that mean level of ambient air lead in major urban cities in India ranged from 0.05 to $1.35 \mu\text{g}/\text{m}^3$ in various centres. Highest concentrations ($1.35 \mu\text{g}/\text{m}^3$) were recorded in Bombay. The findings also showed a positive correlation

between number of automobiles and/or lead based industries with ambient lead levels. One of the most recent studies on air borne heavy metals in India is a study by Chelani et al (2001) in Mumbai atmosphere. Following were range of concentrations of heavy metals (ng/m^3) in RSPM reported by the authors; Cd = 1-180, Cr = 8-180, Ni = 8-170, Zn = 90-2500, Pb = 80-1170. Authors also found that even in Mumbai, a city with highest traffic flow in India and industrial activities, there have been only sporadic measurements of toxic elements in the air environment. Especially information on RSPM associated elements in Indian atmosphere is meagre.

In Calcutta, another major metropolitan city in India, a study conducted by Samanta et al (1998) in five important street crossings found high concentrations of heavy metals in TSP. Range of mean lead concentrations in samples of different stations were 0.64 – 3.49 $\mu\text{g}/\text{m}^3$ with highest value 12.79 $\mu\text{g}/\text{m}^3$. Following are mean range of other metals in TSP recorded by Samanta et al (1998); Cu = 1.13 – 6.57 $\mu\text{g}/\text{m}^3$, Cr = 0.055 – 1.11 $\mu\text{g}/\text{m}^3$, Hg = 0.001 – 0.04, Cd = 0 – 0.05 $\mu\text{g}/\text{m}^3$, Ni = 0 – 1.52 $\mu\text{g}/\text{m}^3$, Mn = 0.37 – 1.4 $\mu\text{g}/\text{m}^3$, Zn = 0.89 – 2.58 $\mu\text{g}/\text{m}^3$ and Fe = 10.28 – 41.56 $\mu\text{g}/\text{m}^3$. No significant correlation was found by authors between air borne lead and vehicle density, and also between air borne cadmium and vehicle number. In Ahmedabad, India, study of air lead concentrations at six traffic junctions of summer and winter indicated that average lead levels are rarely less than 1 $\mu\text{g}/\text{m}^3$ and does not exceed 14 $\mu\text{g}/\text{m}^3$ (Agarwal 1991).

6.3 Methodology

The glass fibre filter after determining the weight and quantifying the RSPM concentrations, were cut into small pieces of known diameter. The cut filter paper pieces were transferred into the Teflon jacketed digestion vials. To this 8ml of nitric acid, 2ml of

hydrofluoric acid and 1ml of perchloric acids were added as suggested by Butler and Alan (1999) and loaded on to the Microwave Digestion System (Milestone Model MLS 1200 and Exhaust Module (EM 45) and digested at 150°C for twenty minutes. After cooling, the digested solutions were filtered using Whatman filter paper (Grade No.1), transferred to plastic measuring cylinders, made up to 15ml with double distilled water and analyzed for lead, copper, chromium, cadmium, zinc and nickel using Atomic Absorption Spectrometer (Model: Perkin Elmer 3300).

In the case of NRSPM, known weight of dust samples were digested in 3ml of concentrated nitric acid and 1 ml of perchloric acid, and left for overnight. The contents were then heated to about 100 degree centigrade for 1 hour, cooled and filtered after rinsing with 3ml 1:1 nitric acid. It was made up to volume with double distilled water and the contents were transferred to clean polyethylene bottles. Using Atomic Absorption Spectrometer the samples were analysed for metals.

6.4 Results

The mean quantum of heavy metals examined in the present study was in the order Zn>Cu>Pb>Ni >Cr>Cd ranging between 0 – 1131 ng/m³ (Table 6.2). Association among the metals is shown in Table 6.3.

Table 6.2 Mean metal concentrations (ng/m³) in sampling stations

Metals	Mean	Std. Deviation	Range in Coimbatore (Present Study)	Range in Mumbai (Chelani et al 2001)
Lead	143.5	271.7	6 – 2147	80 – 1170
Copper	388.6	218.3	43.8 – 973	-
Chromium	14.2	14.1	0 – 87.3	8 – 180
Cadmium	2.8	1.5	0 – 9.1	1–180
Zinc	519.9	179.76	122 – 1131	-
Nickel	31.37	15.29	6.5 – 86.3	-

Table 6.3 Pearson's correlation coefficient between metals.

	Lead	Copper	Cadmium	Chromium	Zinc	Nickel
Lead	1.00					
Copper	0.15	1.00				
Cadmium	0.46**	0.36**	1.00			
Chromium	0.58**	0.29**	0.47**	1.00		
Zinc	0.03	0.23	0.29*	0.08	1.00	
Nickel	0.18	0.21	0.22*	0.05	0.35	1.00

** P< 0.01 , *P< 0.05

6.4.1 Lead

Overall lead concentrations in RSPM during the study period across the sampling stations ranged between 6.7 – 2147 ng/m³. Among the stations, station E (Industrial area) recorded highest concentration of 2147 ng/m³. Figure 6.1 shows lead distribution at various stations with standard deviation and minimum and maximum values. An average of 81% of lead is found in RSPM fraction of TSPM, though it varied between 56% to 91.3% among stations with station D having high fraction of lead in RSPM. Lead level showed significant variation among the stations (Table 6.4), while within stations, between 1st and 2nd year or among seasons no significant variation could be seen.

Table 6.4. ANOVA of lead among stations, seasons and the two study years

Lead	Df	F Value	P<
Between stations	5	13.61	0.00
Between seasons	3	0.664	0.618
Within stations (1999-2000 and 2000-2001)	1	0.59	.442

6.4.2 Copper

Copper concentration in samples of stations ranged between 43.8 – 973 ng/m³ (Figure 6.2). The mean station wise concentrations (ng/m³) were found in order; Station A > Station B > Station D > Station E > Station C > Station F. Highest level was recorded in station E (973 ng/m³) during November 1999, while the lowest value in station F during

November 2001. ANOVA of copper showed significant variations among stations and seasons (Table 6.5).

Table 6.5. ANOVA of copper among stations, seasons and the two study years

Copper	df	F Value	P<
Between stations	5	12.4	0.00
Between seasons	3	5.83	0.00
Within stations (1999-2000 and 2000-2001)	1	0.01	0.92

6.4.3 Chromium

Overall chromium values in all samples ranged from 0 – 87 ng/m³ (Figure 6.3). The mean concentration in the study area was 14.2 ± 14.1 ng/m³. The highest Cr content was noticed in industrial area followed by urban, urban-residential and sub-urban areas. Following are the station wise decreasing trend of mean concentrations; D > B > E > A > C > F. Cr was below detectable limits at stations C and F, while highest levels was recorded in SIDCO (station D) during October 2001. Analysis of variance of Cr showed significantly high variation among stations and the two consecutive study years, but not among the seasons (Table 6.6).

Table 6.6. ANOVA of chromium among stations, seasons and the two study years

Chromium	df	F Value	P<
Between stations	5	23.8	0.00
Between seasons	3	1.793	0.133
Within stations (1999-2000 and 2000-2001)	1	5.1	0.02

6.4.4 Cadmium

The distribution of cadmium in all samples were in the range of 0 – 9.1 ng/m³ (Figure 6.4). The station wise mean concentrations of Cd decreasing order is as follows: D > A > B > E > C > F (Industrial > Urban > Suburban-Highway, Urban-Residential > Suburban). Cd concentrations were below detectable limits at stations C, E and F. The highest value (9.1

ng/m³) of Cd was recorded at station D during February 2002. ANOVA of cadmium concentrations showed that variation is significant among stations while it was not among seasons and the two study years (Table 6.7).

Table 6.7 ANOVA of cadmium among stations, seasons and the two study years

Cadmium	df	F Value	P<
Between stations	5	18.1	0.00
Between seasons	3	0.733	0.5711
Within stations (1999-2000 and 2000-2001)	1	0.41	0.522

6.4.5 Zinc

Zinc in RSPM ranged between 122.2 – 1131 ng/m³ with mean concentration 519.19 ± 79.76 ng/m³ (Figure 6.5). The station wise mean concentrations in decreasing order is as follows: A > B > E > D > F > C. The highest value (1131 ng/m³) and lowest values were recorded at station B and station F during the months of July and March respectively. ANOVA showed significant variation in zinc values among stations while the variation was not significant between the two study years and the seasons (Table 6.8).

Table 6.8 ANOVA of zinc among stations, seasons and the two study years

Zinc	df	F Value	Sig.
Between stations	5	6.05	0.00
Between seasons	3	1.12	0.309
Within stations (1999-2000 and 2000-2001)	1	0.27	0.604

6.4.6 Nickel

Nickel in samples varied between 6.5 – 86.3 ng/m³ with an average concentration of 31.37 ± 15.29 (Figure 6.6). The station-wise mean concentration was in the order; A > B > D > E > C > F. Highest value (86.5 ng/m³) was recorded in station A during December 1999, while the lowest was recorded at station F during April 1999. ANOVA of nickel levels (Table 6.9) showed significant variation among stations and between the two years (1999 –2000 and 2000- 2001).

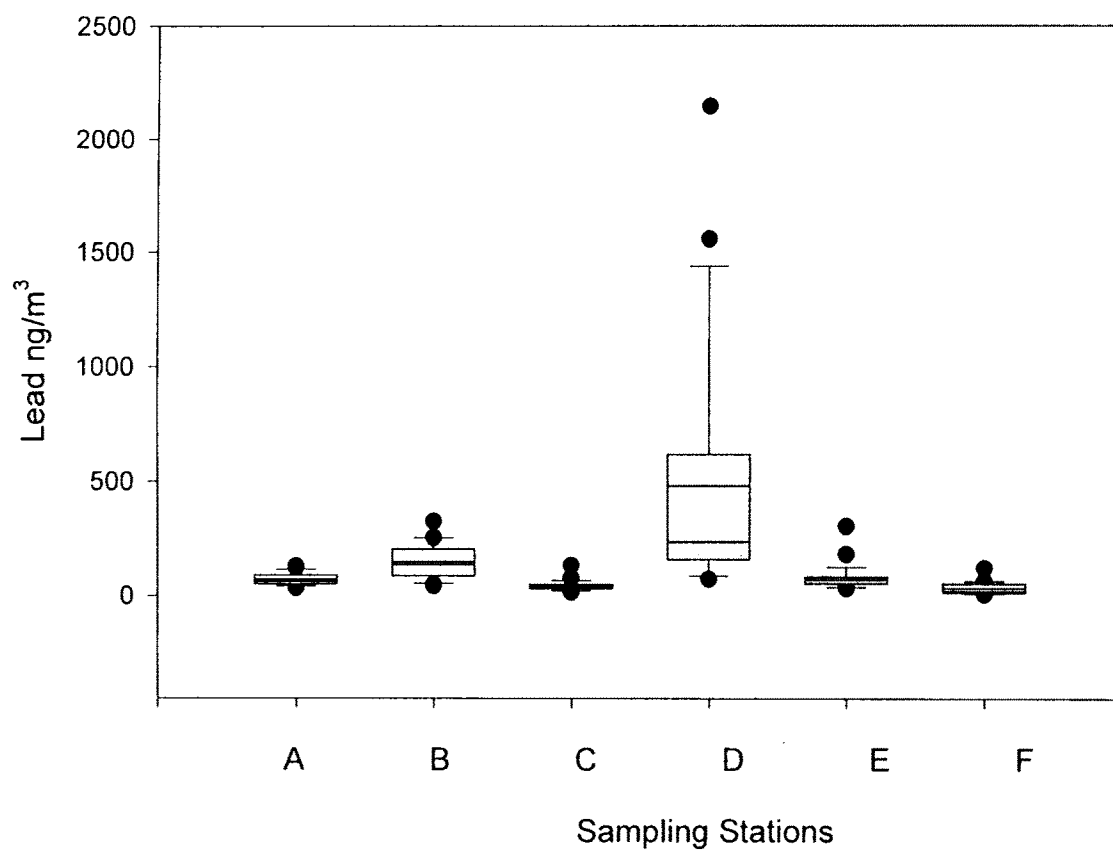


Figure 6.1 Lead distribution in sampling stations A – F (for details on the figure refer the legend of Figure 5.1, Page # 69)

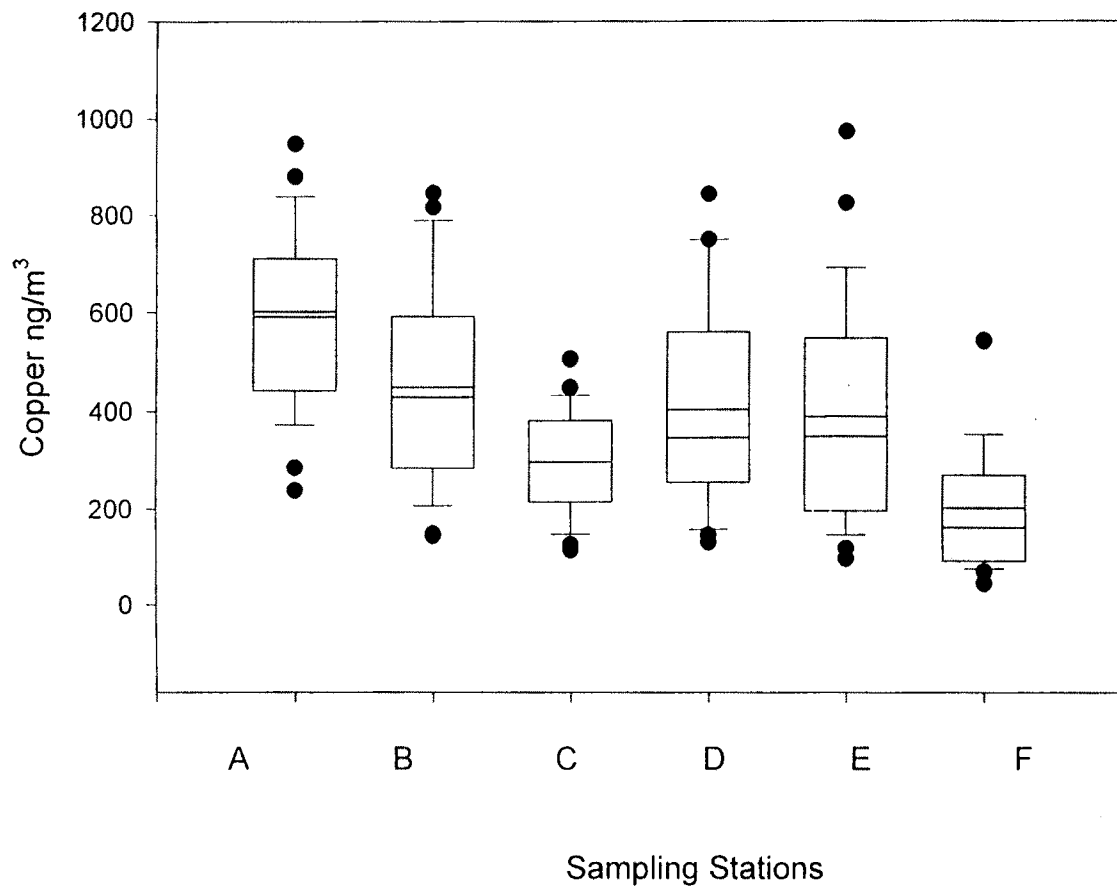


Figure 6.2 Copper distribution in sampling stations A – F (for details on the figure refer the legend of Figure 5.1, Page # 69)

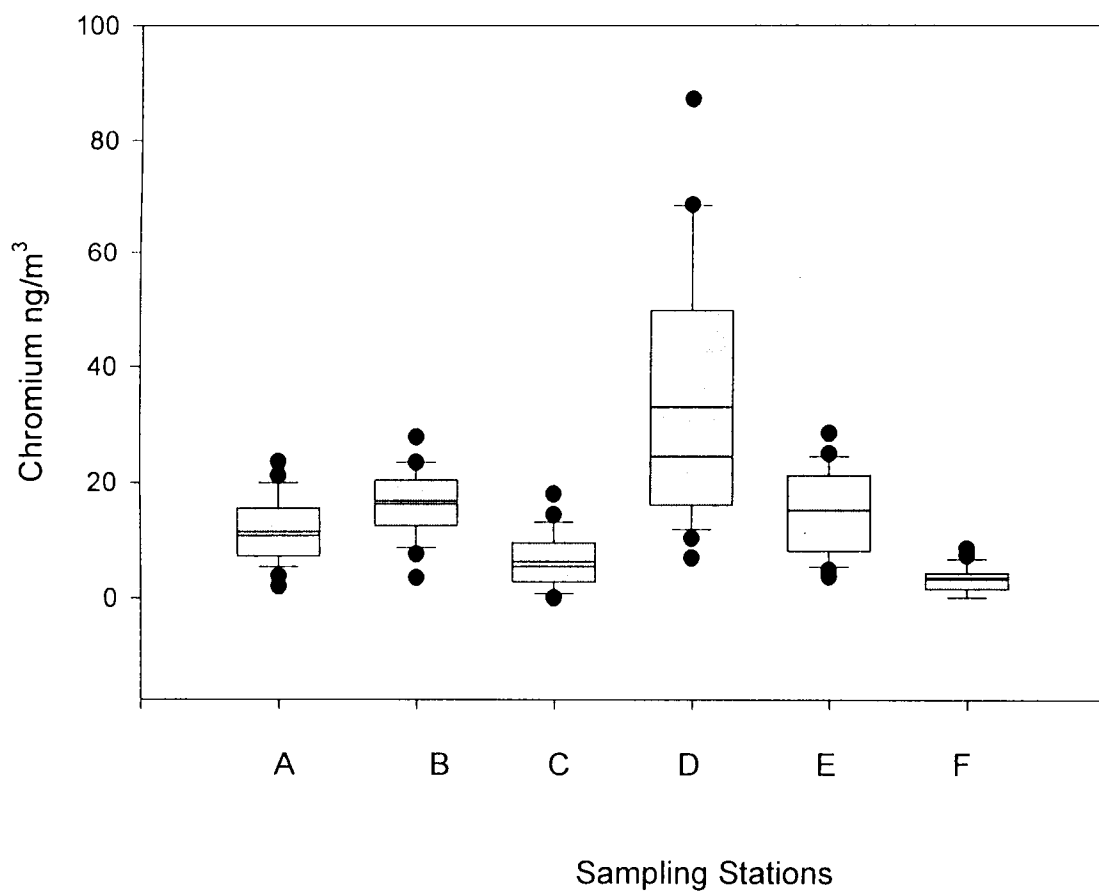
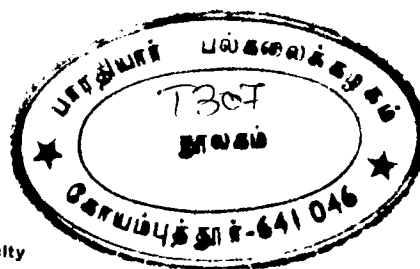


Figure 6.3 Chromium distribution in sampling stations A-F (for details on the figure refer the legend of Figure 5.1, Page # 69)



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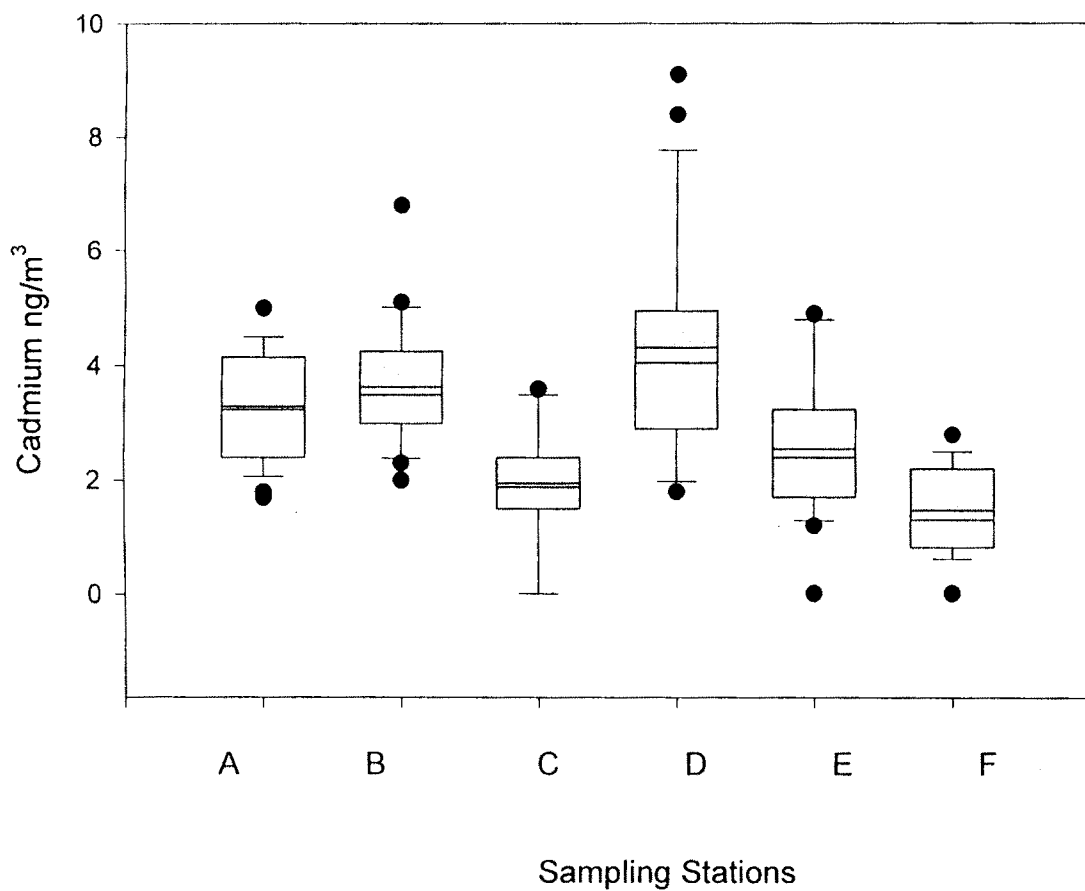


Figure 6.4 Cadmium distribution in sampling stations A- F (for details on the figure refer the legend of Figure 5.1, Page # 69)

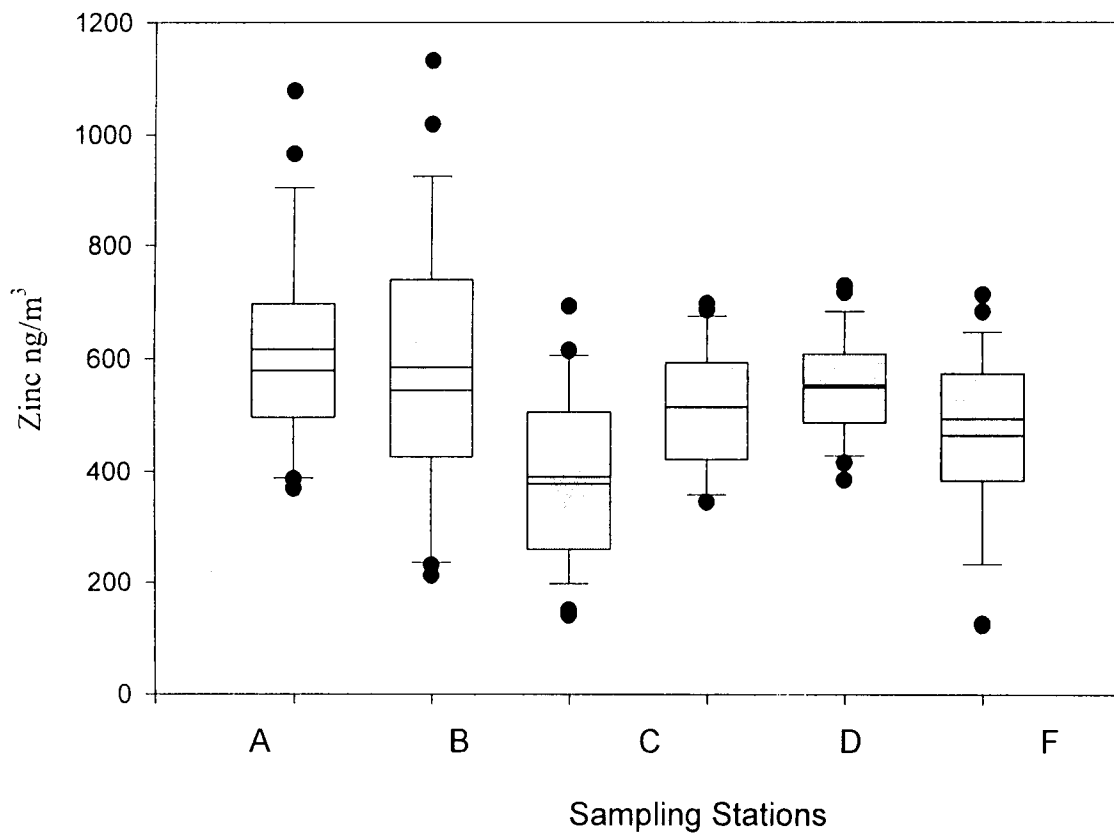


Figure 6.5 Zinc distribution in sampling stations A-F (for details on the figure refer the legend of Figure 5.1, Page # 69)

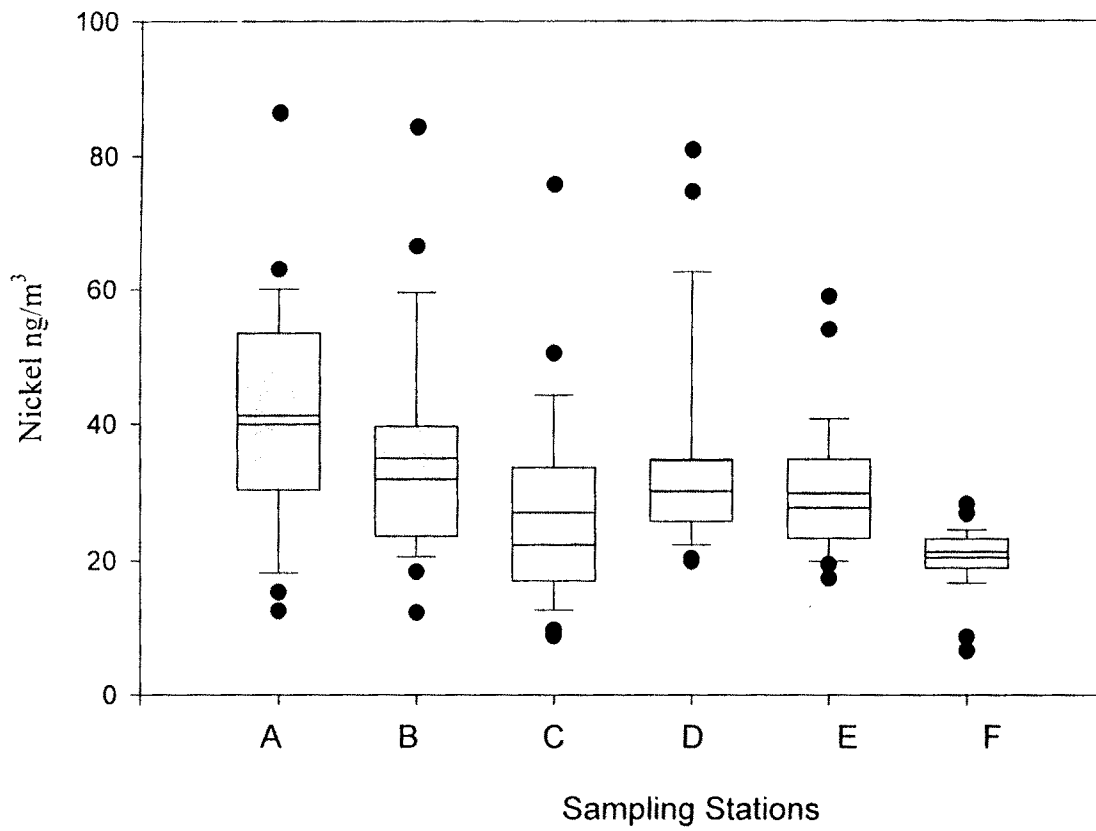


Figure 6.6 Nickel distribution in sampling stations A-F (for details on the figure refer the legend of Figure 5.1, Page # 69)

Table 6.9 ANOVA of nickel among stations, seasons and the two study years

Nickel	Df	F Value	Sig.
Between stations	5	6.456	0.00
Between seasons	3	0.63	0.64
Within stations (1999-2000 and 2000-2001)	1	4.9	0.02

6.4.7 Heavy Metals in NRSPM

The heavy metals associated with NRSPM is not a major interest of the current study. However the concentrations of metals examined are shown in figures 6.15 –6.18. Overall abundance of metals were in the following order Cu> Zn> Pb> Cd. Cu in NRSPM ranged between 9-550.6 ng/m³ with an average 101.8 ± 107.5 ng/m³, Pb ranged between 2.2-254 with an average 33.7 ± 32.5 ng/m³. Zn ranged between 5.7-760 ng/m³ with an average 63.2 ± 77.19 ng/m³, Cd ranged between BDL - 2.8 ng/m³ with an average 0.47 ± 0.38 ng/m³. Table 6.10 shows correlation among metals bound to NRSPM.

Table 6.10 Pearsons correlation co-efficient between metals in NRSPM fraction.

	Cu ng/m ³	Pb ng/m ³	Zn ng/m ³	Cd ng/m ³
Cu ng/m ³	1			
Pb ng/m ³	0.263**	1		
Zn ng/m ³	0.346**	0.714**	1	
Cd ng/m ³	-0.01182	0.243**	-0.07063	1
** P< 0.01				

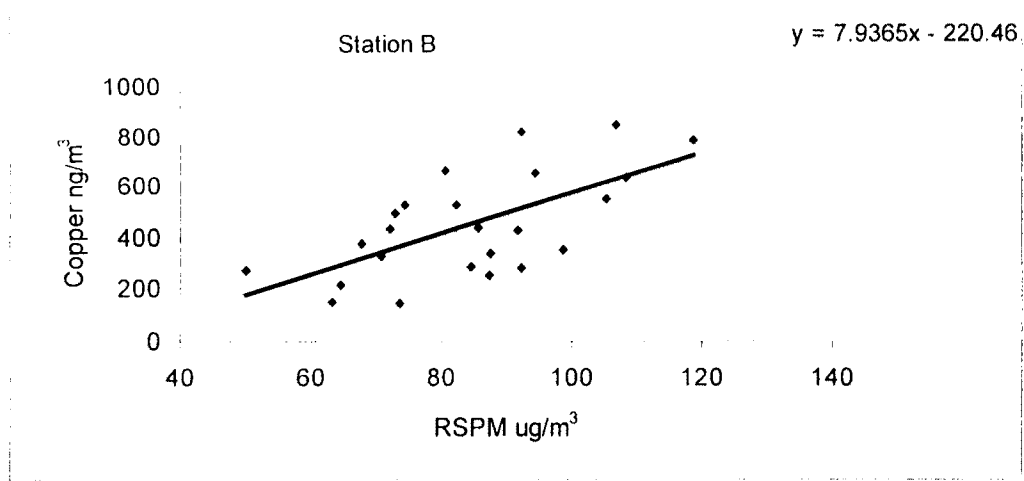


Figure 6.7 Linear regression between RSPM and copper values.

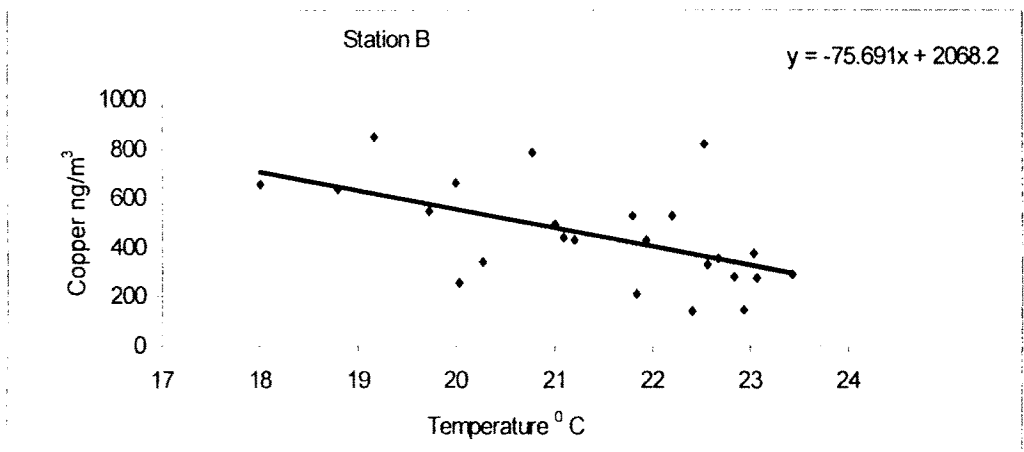


Figure 6.8 Linear regression between temperature (minimum) and copper values

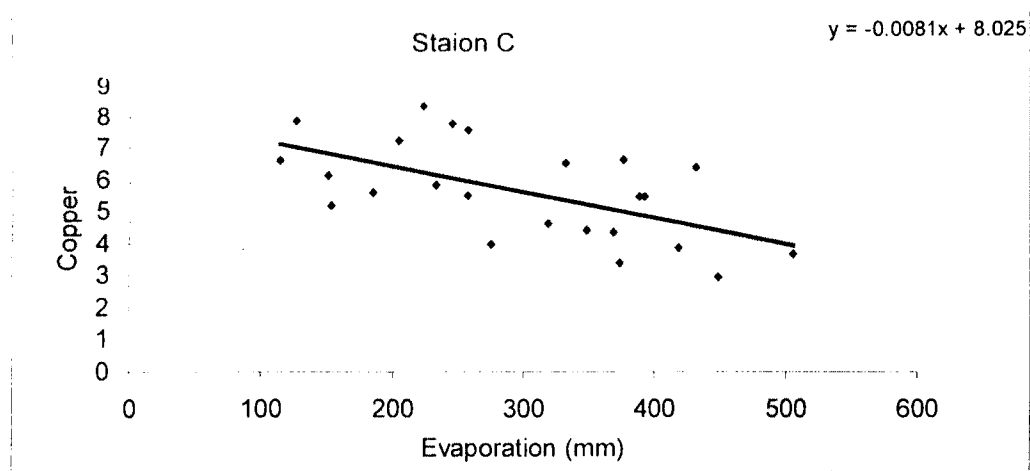


Figure 6.9 Linear regression between evaporation rate and copper values.

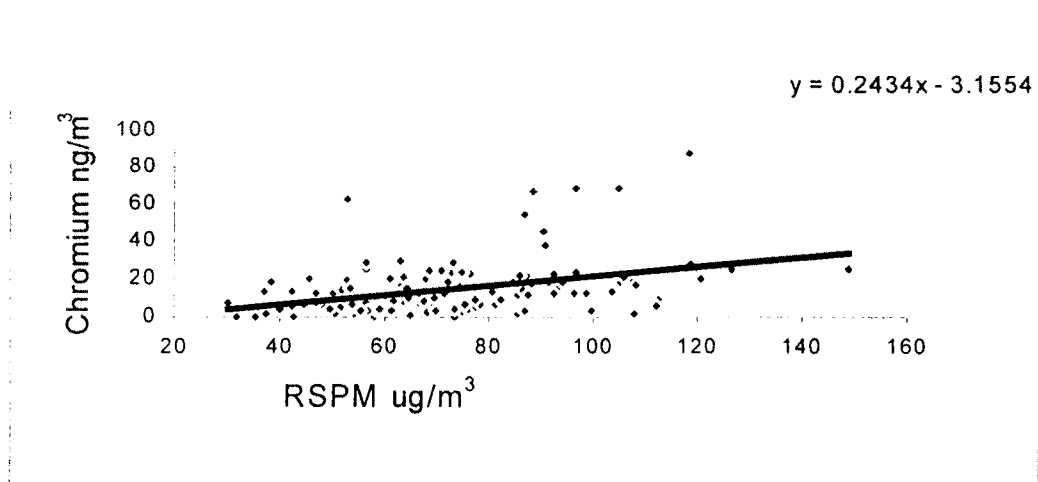


Figure 6.10 Linear regression between RSPM and chromium values.

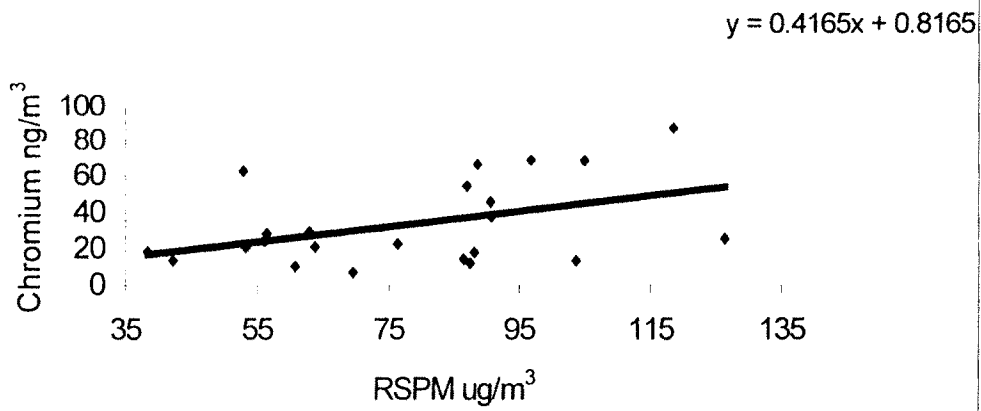


Figure 6.11 Linear regression between RSPM and chromium values in station D

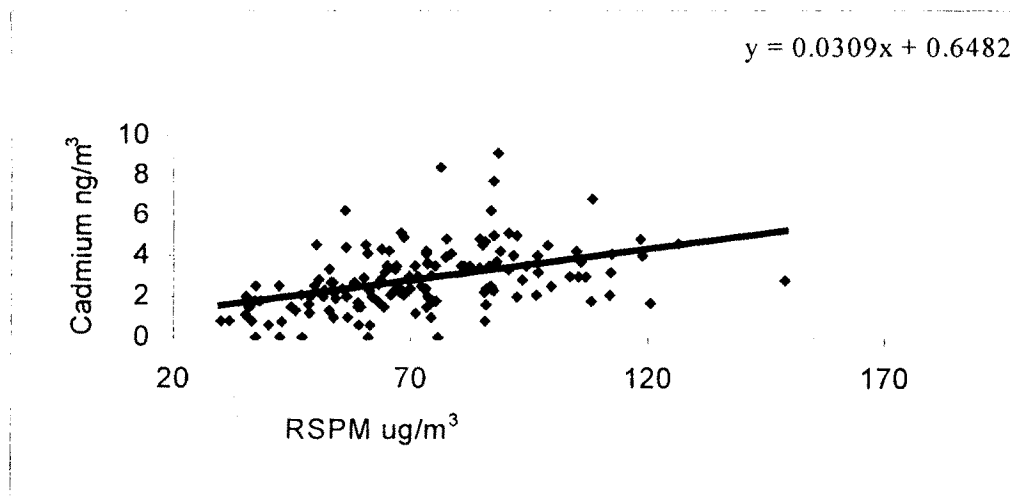


Figure 6.12 Linear regression between RSPM and cadmium.

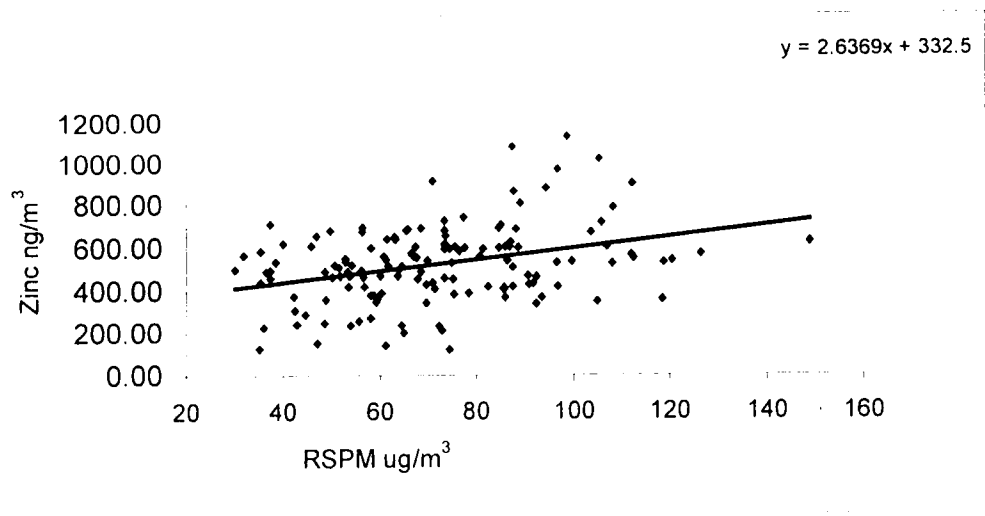


Figure 6.13 Linear regression between RSPM and zinc

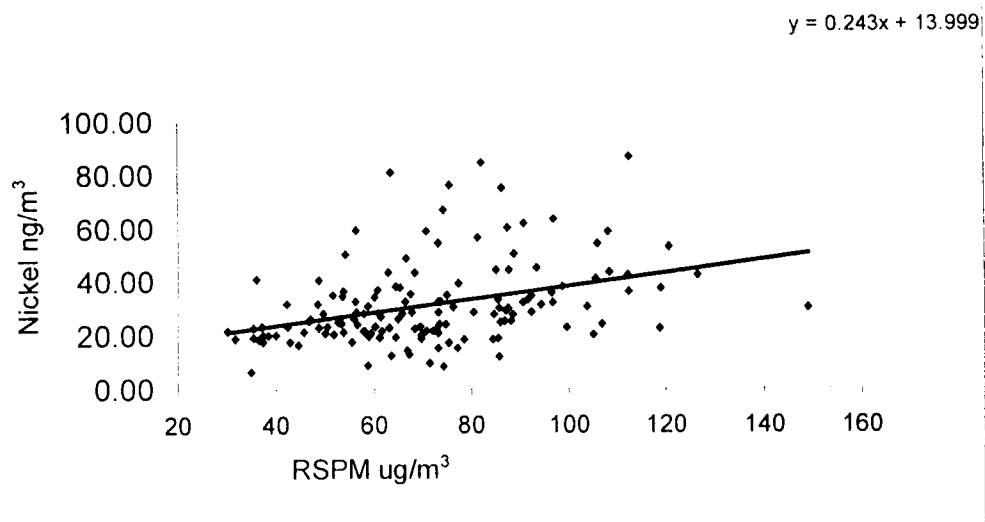


Figure 6.14 Linear regression between RSPM and nickel

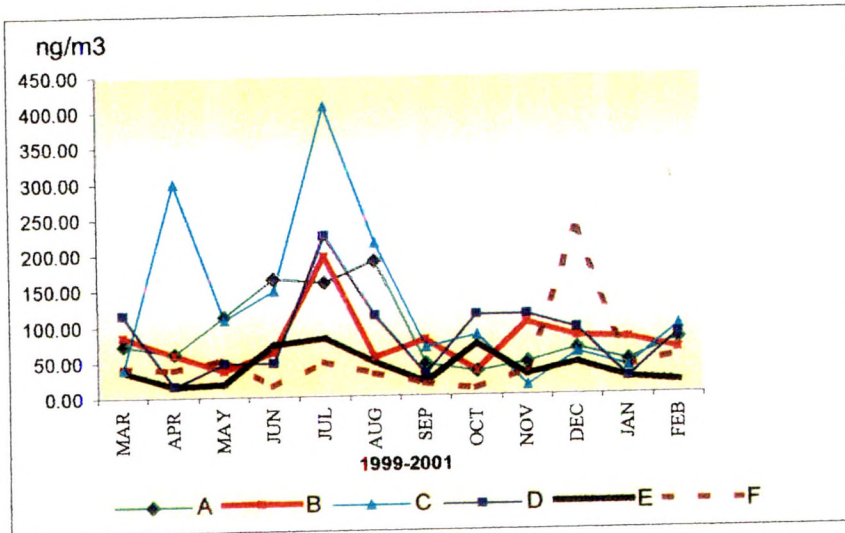


Figure 6.15 Copper in NRSPM

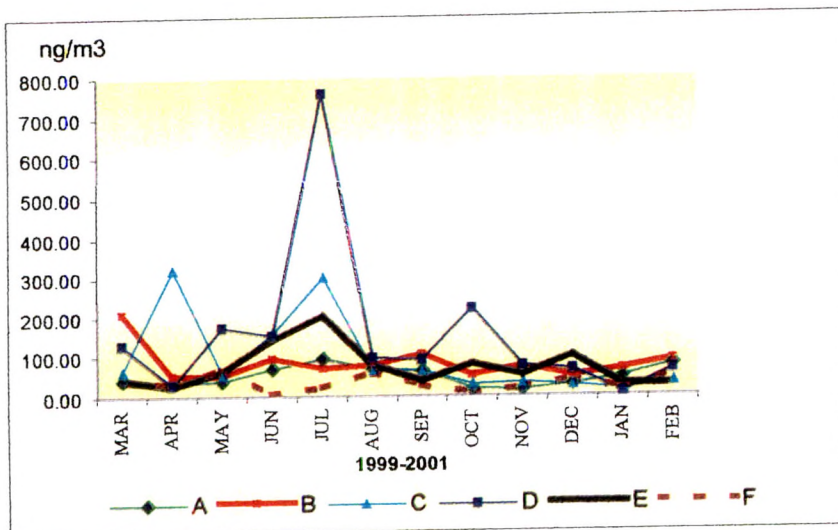


Figure 6.16 Zinc in NRSPM

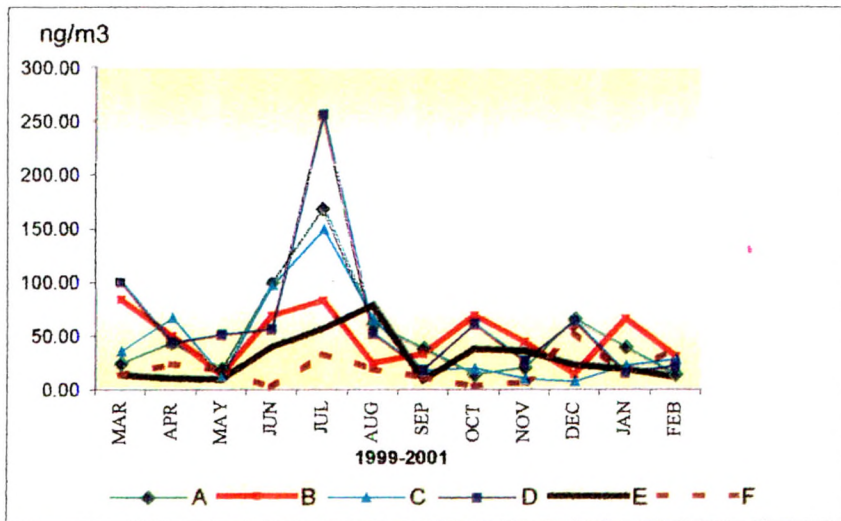


Figure 6.17 Lead in NRSPM

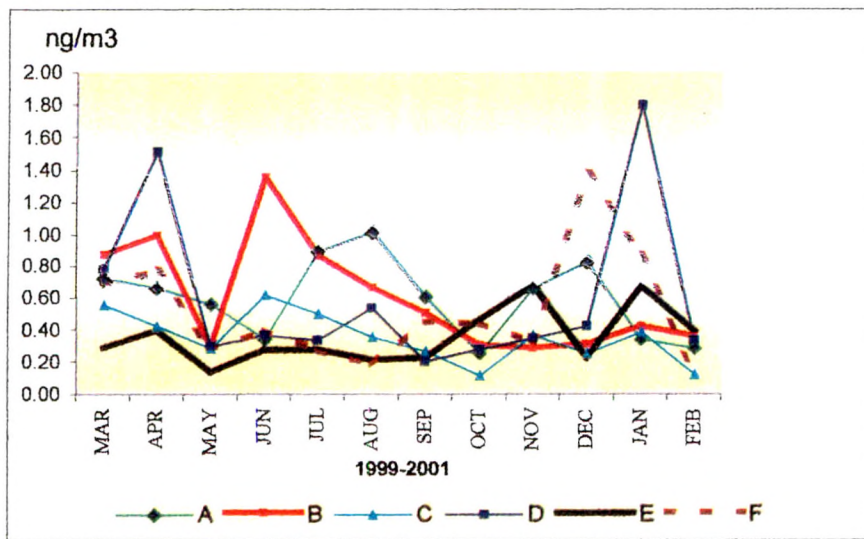


Figure 6.18 Cadmium in NRSPM

6.5 Discussion

An evident positive relation between metals associated with RSPM and RSPM values shows that probably RSPM is the major content carrying air borne metals. Significant positive correlation among metals except lead and copper suggests that mostly they originate from a common source (Table 6.3). Another erstwhile nation wide study of Integrated Programme on Heavy Metal Pollution (IPHM) conducted during April 1983-March 1989 (Krishnamurti and Viswanathan 1991), found strong correlation between zinc and chromium in TSPM ($r = 0.686$, $p < 0.01$). In the current study no relation was found among chromium and metals such as zinc and nickel. RSPM bound metal levels in the current findings, is comparable with a similar study by Chelani et al (2001) in Mumbai (Table 6.2). In their study following range of concentrations of heavy metals (ng/m^3) were found in RSPM; Cd = 1-180, Cr = 8-180, Ni = 8-170, Zn = 90-2500, Pb = 80-1170.

The following paragraphs discuss metal wise details obtained in the present study.

6.5.1 Lead

Highest level of lead (2147 ng/m^3) was recorded SIDCO (Station D). The station also had highest mean value ($481 \pm 544.3 \text{ ng/m}^3$). As mentioned earlier such wide monthly variation in lead levels indicates the importance of industrial operations in determining the ambient concentrations of lead. In SIDCO, except for the temperature (minimum) that had a negative correlation with lead levels ($r = -0.45$, $p < 0.01$), no other meteorological factors were found to be influential. Positive correlation observed among lead and other heavy metals (Cd, Cr) in SIDCO indicate to the common source for these elements.

In station A, lead levels having significant positive relationship with wind speed ($r= 0.5$ $p<0.05$) and NRSPM levels ($r= 0.51$, $p<0.01$) probably denotes that re-suspension of road dust as a major source. In Station B, which had mean lead concentration of 149.2 ± 76 ng/m^3 , no significant relationship was found with meteorological factors and SPM. In station C, lead concentration ranged between $16.2 - 133.2$ ng/m^3 with an average of 43.2 ng/m^3 . No association of lead was found with any of the meteorological parameters in station C. An average of 81.4 ± 56.9 ng/m^3 of lead is found in station E with significant correlation with RSPM values ($r= 0.6$, $p< 0.01$). Station F recorded the lowest mean of lead compared to other stations, which also had comparatively less urban activities and vehicular movement. In Station F, lead values showed significant positive relationship with RSPM ($r= 0.66$, $p< 0.01$) and negative relationship wind speed ($r= -0.42$, $p< 0.05$). The overall pattern of lead distribution shows industrial operation as a major source in SIDCO, while in other places vehicular emission may have a major role. Leaded petrol causes about 90% of airborne lead pollution in cities, the rest of which comes from factories, power plants, lead pipes, lead based solar and paint (Down to earth 1997a). In India, lead free gasoline has been introduced throughout the country since February 1, 2000, and in all metropolitan cities since 1995. This might have resulted in a downward trend in the lead concentrations in the ambient air (CPCB 2000).

In general, on an assumed average concentration of 200 $\mu\text{g/m}^3$ Pb in air, the intake of lead can be calculated to range from 0.5 $\mu\text{g/day}$ for an infant to 4 $\mu\text{g/day}$ for an adult (Irwin 1997). In developing countries about 15 million children may be suffering from permanent brain damage due to lead poisoning. About 80% of the children aged between three and five living in urban areas have blood lead levels, which exceed the health standards prescribed by WHO (Irwin 1997). A study in five mega cities in India showed that among 1852 children tested, 51.4% had blood lead levels above 10 $\mu\text{g/dl}$. The

percentage of children having 10 $\mu\text{g}/\text{dl}$ or higher blood lead levels ranged from 39.9% in Bangalore to 61.8% in Mumbai (CPCB 2000).

6.5.2 Copper

In the case of copper on an average about 79% occurred in RSPM fraction of TSPM. The urban samples of station A and B had it comparatively higher in RSPM fraction (about 85%). Significant variation in copper concentration was observed among the stations (Table 6.5), while within stations no significant variation between 1st and 2nd year of the study was observed. But the variation was significant among seasons indicating the influence of meteorological parameters. This finding probably also reflects variation in background urban activities and volume of traffic between stations.

Over all copper levels irrespective of stations showed increasing values with increase in RSPM concentrations ($r= 0.58$, $p < .01$) probably indicating RSPM as a major repository for copper. Copper had positive correlations with other metals such as Cr and Cd ($r= 0.29$, $p < 0.05$ and $r= 0.36$, $p < 0.05$ respectively). In station B, very high positive relation was observed with RSPM (Figure 6.7). The increase in temperature (minimum) also had negative relation (Figure 6.8). At station C, significant relationship was observed between copper and evaporation rate (Figure 6.9). In station E, no meteorological parameters had significant relationship. IHPM study in India (Krishnamurti and Viswanathan 1991), detected copper in SPM of all city samples except a few samples in Uttar Pradesh, Bihar, Gujarat and Rajasthan. Concentration as high as $44.02 \mu\text{g}/\text{m}^3$ was observed in an air sample from Gujarat followed by one from Uttar Pradesh (Urban) in winter ($36.8 \mu\text{g}/\text{m}^3$). The air samples from Tamilnadu had showed concentrations ranging from 0.16 – $6.91 \mu\text{g}/\text{m}^3$, however the mean and median in all samples were $1.214 \mu\text{g}/\text{m}^3$

and $0.898 \mu\text{g}/\text{m}^3$ respectively. The current levels in Coimbatore ($0.0438 - 0.973 \text{ ng}/\text{m}^3$) also fall within the range.

6.5.3 Chromium

Chromium had positive relationship with RSPM (Figure 6.10). In station D, the relationship was comparatively significant (Figure 6.11). No statistically significant association was found between chromium and meteorological parameters. In IPHM study (Krishnamurti and Viswanathan 1991), chromium concentrations in Tamilnadu ranged between $0.002 - 0.09 \mu\text{g}/\text{m}^3$. Highest concentration of Chromium in RSPM of the current study is equivalent to Tamilnadu's highest concentration of Chromium in TSPM of IHPM study indicating the increasing trend of Cr in Coimbatore air. In Kerala, Rajasthan and Karnataka, IPIIM study reported the maximum concentration less than $0.1 \mu\text{g}/\text{m}^3$, while in other states it was between 0.1 and $1 \mu\text{g}/\text{m}^3$. Overall mean and median values in various samples of India ranged between $0.016 - 0.21 \mu\text{g}/\text{m}^3$ and $0.008 - 0.11 \mu\text{g}/\text{m}^3$ respectively. The highest concentration of Cr was in an SPM sample collected in Chandigarh ($3.43 \mu\text{g}/\text{m}^3$) followed by one in Haryana ($1.06 \mu\text{g}/\text{m}^3$).

6.5.4 Cadmium

In TSPM an average of 86% of cadmium is present in RSPM without much variation between samples. Statistically the variation among the stations was significant (Table 6.6). Significant positive correlation was observed between cadmium and RSPM ($r = 0.44$, $p < .01$, Figure 6.12). In IPIIM study (Krishnamurti and Viswanathan 1991), Cd concentration in Tamilnadu, varied between $0.004 - 0.02 \mu\text{g}/\text{m}^3$ with a mean concentration of $0.006 \mu\text{g}/\text{m}^3$ in TSPM. Cd values of the ($0-0.009 \mu\text{g}/\text{m}^3$) current study also falls in the range. The maximum concentration of Cd was observed in West Bengal

(0.27 $\mu\text{g}/\text{m}^3$).

6.5.5 Zinc

A positive correlation was observed between RSPM and Zinc associated with RSPM probably indicating RSPM as major carrier of zinc ($r = 0.32$, $p < 0.01$, Fig 5.13). No significant association was found between meteorological parameters and zinc values in RSPM. In IPHM study (Krishnamurti and Viswanathan 1991), a very high concentration of zinc ($109.5 \mu\text{g}/\text{m}^3$) was observed in SPM sample collected in urban Hyderabad. In Tamilnadu in zinc SPM samples ranged between $0.016 - 0.838 \mu\text{g}/\text{m}^3$. The current levels of zinc in RSPM of Coimbatore ($0.122 - 1.131 \mu\text{g}/\text{m}^3$) indicate a notable rise compared to IPHM study. Among stations significant variations was found between the two study years. However, no significant change was observed between seasons (Table 6.8). No significant relationship was also observed between zinc and meteorological parameters.

6.5.6 Nickel

Nickel bound to RSPM is positively related with RSPM ($r = 0.36$, $p > 0.01$). The linear regression is shown in Figure 6.14. In India, IPHM study has reported highest concentration of $6.7 \mu\text{g}/\text{m}^3$ in Uttar Pradesh during winter (Krishnamurti and Viswanathan 1991). Some other significant figures were $3.2 \mu\text{g}/\text{m}^3$ from Chandigarh, $2.34 \mu\text{g}/\text{m}^3$ from Andhra Pradesh and around $1 \mu\text{g}/\text{m}^3$ from Tamilnadu, Bihar and Punjab. In all other states the highest concentration observed was less than $1 \mu\text{g}/\text{m}^3$.

No significant correlation was observed for certain metals (Pb, Cu and Cd) between the respirable fraction and non-respirable fraction. This probably suggests that fugitive road dust might be a major source for metal in non-respirable fraction, while emissions from other sources might be a major contributor to the metals in respirable fraction. For metals,

Cu, Pb and Zn positive relation with its NRSPM fraction strengthens the belief that fugitive dust that settles within a short duration as a major source for the metals in NRSPM (Table 6.10).

6.6 Summary and Conclusions

Heavy metals associated with RSPM and NRSPM were estimated in air samples from six stations in Coimbatore during March 1999 to February 2001. The mean quantity of heavy metals in RSPM was in the order $Zn > Cu > Pb > Ni > Cr > Cd$. Concentrations of these heavy metals were in the range BDL – 2147 ng/m³ in RSPM. Highest level of lead (2147 ng/m³) was recorded Station D (industrial area). The station also had highest mean value (481±544.3 ng/m³) suggesting the importance of industrial operations in determining the ambient concentrations of lead. Significant positive correlation among metals excepting lead and copper suggests that mostly they originate from a common source. Air samples of urban and industrial areas showed higher concentrations than residential (Urban) and suburban areas.

NRSPM bound heavy metals were in the following range; Cu = 9-550.6 ng/m³, Pb = 2.2-254.8 ng/m³, Zn = 5.7-760, 0-2.9 ng/m³, Cd = 0 – 2.8 ng/m³. The abundance of metals (mean concentrations ng/m³) were in the order Cu = 101.8 + 107.5 > Zn = 63.2 + 77.19 > Pb = 33.7 = 32.5 > Cd = 0.47 + 0.38. In TSPM an average of 81% of lead, 89% of zinc, 86% of cadmium and 79% of copper were found in RSPM fraction. No significant correlation was observed among the heavy metals and meteorological parameters.

In general it may be concluded that the atmospheric concentrations heavy metal recorded in the current study falls in normal range reported elsewhere in urban areas. However, the current pace of vehicular growth and urban development metals like lead, zinc and copper

may reach a higher pollution level. Certain metals like chromium, cadmium, and zinc showed increasing trend compared to earlier studies in Coimbatore.

CHAPTER –7

Water Soluble Cations and Anions in RSPM

7.1 Introduction

Inorganic constituents of particulate matter are contributed by both natural (soil origin) and anthropogenic sources like combustion of fossil fuels (Rao et al 2001). Acidic aerosols like sulfate and nitrates in air are linked with increasing hospital admissions for respiratory disorders and even mortality. Particle bound ions, especially sulphate particles are known to influence direct radiative forcing (IPCC 2001, Penner et al In Press). The deposition of inorganic aerosols may induce a response on soil and water ecosystems e.g. by acidification and accumulation of metals (Ali-Mohamed 1991). Wide spread acidification of both aquatic and terrestrial ecosystems was first observed in parts of Scandinavia during 1960's and 1970's due to deposition of acidic aerosols (Goudie and Cuff 2002). In India, higher deposition rates of acidic aerosols are observed in winter than summer in western UP, India (Satsangi et al 1999). Despite the reductions in SO₂ sources mandated by Clean Air Act Amendments large sulfate depositions are still observed in eastern America (Stein and Lamb 2000).

7.2 Background

7.2.1 Characteristics and atmospheric concentrations of inorganic constituents

The water-soluble inorganic constituents of particulate matter mainly consist of nine major ionic components: Na⁺, K⁺, NH₄, Ca²⁺, Mg²⁺, H⁺, SO₄, NO₃ and Cl⁻. These inorganic constituents of PM 10 and PM 2.5 vary according to country, region, season and industrialization. In a typical UK atmosphere in PM 2.5 fraction, next to carbonaceous matter, sulphates comprise most abundant fraction followed by nitrates, ammonium and chlorides (Hext et al 1999). Measurements by US Environmental

Protection Agency indicate that the fine particulate mass in eastern US contained about 50% or more inorganic constituents mostly sulfate, nitrate and ammonium (EPA 1996). Ali-Mohamed (1991) reported that five major ionic components; Na^+ , Ca^{2+} , Mg^{2+} , H^+ , Cl^- , NO_3^- formed 52.99% of the total aerosol mass collected in outskirts of one expanded town in Bahrain. Waldman and Lioy (1990) showed that in Toronto urban atmosphere, NH_4^+ and SO_4^{2-} ions are primarily the major inorganic portion of the aerosol and several episodes of aerosol acidity and elevated SO_4 was observed at all sampling sites. Aerosols at high elevation sites at the mountains of southern slope of Himalayas and Tibetan plateau were dominated by NH_4 , SO_2 , NO_3 and Ca species (Wake et al 1994). Some recent reports on major ionic constituents of particulate matter are shown in Table 7.1.

Table 7.1 Ionic constituents of particulate matter at various places

Location of the study	Concentrations of inorganic constituents in PM and observations	Author
Taipei, Taiwan	In PM 10 fraction (ng/m^3): Cl = 4981, Ca = 4157, K = 2384. In PM 2.5 fraction, Cl, K, and Ca recorded 1551, 1250, and 2357 ng/m^3 respectively as dominant elements.	Li and Hsu (1993)
Urban and non-urban areas of Netherlands	During winter mean sulfate, nitrate and ammonium were 8 $\mu\text{g}/\text{m}^3$, 4 $\mu\text{g}/\text{m}^3$ and 4.5 $\mu\text{g}/\text{m}^3$ respectively.	Zee et al (1998)
Leeds, UK	In PM 10 content: Sulphate = 4.75 $\mu\text{g}/\text{m}^3$, Chloride = 1.26 $\mu\text{g}/\text{m}^3$ respectively. Sulphate distribution was mainly in fine particles though a significant amount is seen in coarse particles also. Nitrate and chloride was observed more in coarser fraction.	Clarke et al (1999)
Zagreb, Croatia	In PM 2.5 fraction; $\text{SO}_4 = 5.26 \pm 4.31 \mu\text{g}/\text{m}^3$, $\text{NO}_3 = 3.14 \pm 3.46 \mu\text{g}/\text{m}^3$, Cl = $0.32 \pm 0.37 \mu\text{g}/\text{m}^3$.	Cackovic et al (2001)
Residential and Urban areas of Cedex, France	In summer-spring SO_4 range = 1 – 14.5 $\mu\text{g}/\text{m}^3$ (Mean = 3.36 $\mu\text{g}/\text{m}^3$) NO_3 range = 1 – 32 (Mean = 4.76 $\mu\text{g}/\text{m}^3$)	Giroux et al (1997)

	<p>Cl range = 0.8 – 16 $\mu\text{g}/\text{m}^3$ (Mean = 6.1 $\mu\text{g}/\text{m}^3$) In winter-autumn $\text{SO}_4 = 0.5 - 20.5 \mu\text{g}/\text{m}^3$ (Mean = 6.3 $\mu\text{g}/\text{m}^3$) $\text{NO}_3 = 0.8 - 27 \mu\text{g}/\text{m}^3$ (Mean = 4.8 $\mu\text{g}/\text{m}^3$) $\text{Cl} = 0.7 - 43 \mu\text{g}/\text{m}^3$ (Mean = 9.1 $\mu\text{g}/\text{m}^3$)</p>	
Eastern Himalayas and Tibetan Plateau	<p>Mean range (ng scm^{-1}) Cl = <0.5 – 69, $\text{SO}_4 = 2.1 - 104$, $\text{NO}_3 = 0.16 - 13$, $\text{NH}_4 = 2.9 - 8.6$, Mg = <0.07 – 38, and Ca = 0.5 – 206.</p>	Wake et al (1994)
Edmonton and Calgary, Canada.	<p>In PM 2.5 mean concentrations; $\text{SO}_4 = 1.45 \mu\text{g}/\text{m}^3$, $\text{NO}_3 = 0.5 \mu\text{g}/\text{m}^3$. In PM 10 mean concentrations were; $\text{SO}_4 = 1.71 \mu\text{g}/\text{m}^3$, $\text{NO}_3 = 0.69 \mu\text{g}/\text{m}^3$.</p>	Cheng et al (1998)
Agra, India	<p>The mean concentrations of ions (ng/m^3) were; Na = 334, K = 357, Ca = 316, Mg = 113.7, $\text{NH}_4 = 1063$, F = 82.3, Cl = 316.4, $\text{NO}_3 = 1134$, $\text{SO}_4 = 1216$. Ratios of Ca/Mg, Cl/Mg and Na/Mg in aerosols are close to corresponding ratios in local soil, while SO_4/Mg, K/Mg and NO_3/Mg ratios in aerosols were higher than in soil ratio. A major part of Ca (52.4 %) and Mg (54.6%) were present in coarse mode representing soil-derived particles.</p>	Parmar et al (2001)

According to West et al (1999) reductions in sulfate concentration may cause an increase in aerosol nitrate. In eastern US, during the measurements made from 1988 to 1990, conditions for such nonlinear response are found to be common in winter and uncommon in summer. Patterson and Eatough (2000) showed outdoor atmospheric sulfate, nitrate, soot, and total particulate number correlating strongly with indoor levels. For particulate sulphate it was found that the winter penetration factor into private residences in Boston (UK) was 0.99 ± 0.033 . In the case of nitrate, penetration factor is substantially less than sulfate.

7.3 Methodology

A part of glass fibre filters carrying RSPM were cut into small pieces of known area and agitated for 6 hr using an agitator with 50 ml of distilled water in a conical flask for

extracting water-soluble constituents of particulates. After 6 hr the samples are centrifuged at 1500 rpm for 15 minutes and the supernatant was transferred to a 50 ml storing bottle and refrigerated. This supernatant solution is used for the analysis of cations and anions following standard methods (Greenberg et al 1992, Table 7.2).

Table 7.2 Parameters analysed and instrumental methods adopted

Parameters	Instrumental method
Sulphate	Turbidimetric
Chloride	Titrimetric
Nitrate	Spectrophotometric
Phosphate	Spectrophotometric
Sodium	Flamephotometric
Potassium	Flamephotometric

7.4 Results

The concentrations of the inorganic constituents in RSPM were in the order; Sulphate > Chloride > Sodium > Potassium > Phosphate > Nitrate. Most of the cations and anions showed positive correlation among them (Table 7.3).

Table 7.3 Correlation among cations and anions in the samples

Parameters	Sulphate	Sodium	Potassium	Chloride	Nitrate	Phosphate
Sulphate	1					
Sodium	0.38**	1				
Potassium	0.31**	0.16	1			
Chloride	0.213*	0.24**	0.096	1		
Nitrate	0.315**	0.253**	0.245**	0.035827	1	
Phosphate	0.32**	0.117	0.27**	0.152	0.37**	1

** P < 0.01, * P < 0.05

7.4.1 Sulphate

Sulphate in RSPM showed a wide range of variation between 0.35 – 11.4 $\mu\text{g}/\text{m}^3$ (Figure 7.1) with a mean concentration of 4.03 ± 2.29 . Highest concentration (11.4 $\mu\text{g}/\text{m}^3$) was

seen in industrial area (Station D). No significant relation was obtained between sulphate values and meteorological parameters. The relationship assumed to be linear between the sulphate and RSPM at each station is shown in Table 7.4. Sulphate values showed significant variation among stations and between two study years, while the variation was not significant among seasons (Table 7.5).

Table 7.4 Relationship between the sulphate and RSPM

Stations	Linear relation between sulphate and RSPM	R ²	P<
Station A	Sulphate = 0.0287 RSPM + 2.5928	0.0871	.01
Station B	Sulphate = 0.0454 RSPM + 1.9863	0.1608	.01
Station C	Sulphate = 0.054 RSPM - 0.1825	0.292	.01
Station D	Sulphate = 0.0671 RSPM - 0.1958	0.402	.01
Station E	Sulphate = 0.0687 RSPM - 1.0145	0.545	.01
Station F	Sulphate = 0.0305 RSPM - 0.0573	0.345	.01

Table 7.5 ANOVA of sulphate among stations seasons and the two study years

Sulphate	df	F Value	P<
Between stations	5	17.737	0.00
Between seasons	3	2.6	0.64
Within stations (1999-2000 and 2000-2001)	1	4.9	0.038

7.4.2 Nitrate

Nitrate in samples ranged between of 10.22 – 425.25 ng/m³ with an average of 150.7 ± 88.14 ng/m³ (Figure 7.2). Station wise nitrate concentration are as follows; A = 235.9 ± 94.79 ng/m³, B = 188.9 ± 67.1 ng/m³, C = 125.7 ± 74.3 ng/m³, D = 113.6 + 66.3 ng/m³, E = 160 ± 78 ng/m³, F = 79.6 ± 47 ng/m³. Highest and lowest values were recorded at station A (Urban) and station D (Industrial) respectively. Substantially significant variation in nitrate concentrations was found among stations. However, nitrate values

showed no statistically significant variation between the two study years or seasons (Table 7.6).

Table 7.6 ANOVA of Nitrate among stations, seasons and the two study years

Nitrate	Df	F Value	P<
Between Stations	5	25.3	0.00
Between Seasons	3	2.25	0.067
Within Stations (1999-2000 and 2000-2001)	1	0.47	0.829

Among the analysed inorganic constituents nitrate showed positive correlation with sulphate, sodium and potassium (Table 7.2). Nitrate showed significant positive relationship with RSPM (Figure 7.8). Meteorological parameters showed no significant influence on the quantity of nitrate in the RSPM.

7.4.3 Phosphate

Phosphate concentration in RSPM ranged between 20.5 – 1193 ng/m³ with an average of 287.79 ± 196.8 ng/m³ (Figure 7.3). Station wise abundance in ranged in order; A > B > D > E > C > F (Urban > Industrial > Urban Residential/ Sub-urban). Highest phosphate was recorded in station B (Urban), while lowest in station F (Rural/Suburban). Phosphate concentrations showed significant variations between stations, seasons and the two study years (Table 7.7). Phosphate showed positive relationship with sulphate, potassium and nitrate. It also showed positive relationship with RSPM (Figure 7.9)

Table 7.7 ANOVA of Phosphate among stations, seasons and the two study years

Phosphate	Df	F Value	P<
Between Stations	5	10.84	0.00
Between Seasons	3	3.938	0.005
Within Stations (1999-2000 and 2000-2001)	1	3.698	0.048

7.4.4 Chloride

The chloride in RSPM samples ranged between 0.5 – 9.8 $\mu\text{g}/\text{m}^3$, averaging $3.19 \pm 1.9 \mu\text{g}/\text{m}^3$ (Figure 7.4). Highest value (9.8 $\mu\text{g}/\text{m}^3$) as well as highest mean ($5.8 \pm 2.26 \mu\text{g}/\text{m}^3$) was recorded in station D (Industrial). Highly significant variation was observed between chloride content at various stations and also between the two study years (Table 7.8). The variation was not significant among seasons. Correlation between meteorological parameters also did not appear significant.

Table 7.8 ANOVA of chloride among stations, seasons and two study years

Chloride	Df	F Value	P<
Between Stations	5	25.39	0.00
Between Seasons	3	7.19	0.008
Within Stations (1999-2000 and 2000-2001)	1	1.52	0.2

7.4.5 Sodium

Sodium content was recorded in the range 0.23 – 6.9 $\mu\text{g}/\text{m}^3$ with an average of 1.87 (Figure 7.5). Highest and lowest values were recorded in station A (Urban) and station C (Urban – residential) respectively. Sodium concentrations also varied significantly among stations and between two study years. However the variation was not significant among seasons (Table 7.9). Alike other ionic constituents sodium was positively correlated with RSPM values (Figure 7.11), chloride, nitrate and sulphate (Table 7.2).

Table 7.9 ANOVA of sodium among stations, seasons and two study years

Phosphate	Df	F Value	P<
Between Stations	5	10.84	0.00
Between Seasons	3	3.938	0.005
Within Stations (1999-2000 and 2000-2001)	1	3.698	0.048

7.4.6 Potassium

Potassium in samples ranged between 0 (below detectable limit) – 2.89 $\mu\text{g}/\text{m}^3$ (Figure 7.6) with an average of $1.09 \pm 0.65 \mu\text{g}/\text{m}^3$. Samples of station E, which lie close to highway, recorded comparatively higher mean as well as highest value of potassium (2.89 during October 2001). Overall station wise mean abundance varied in following order; E > B > D > A > C > F. There was significant variation in potassium values among stations. However no significant variation was observed between the two study years and also seasons (Table 7.10). No significant association was noticed between potassium values and meteorological parameters. The relationship between potassium and RSPM is shown in Figure 7.12

Table 7.10 ANOVA of Potassium among stations, seasons and two study years

Potassium	Df	F Value	P<
Between Stations	5	10.84	0.00
Between Seasons	3	3.938	0.005
Within Stations (1999-2000 and 2000-2001)	1	3.698	0.048

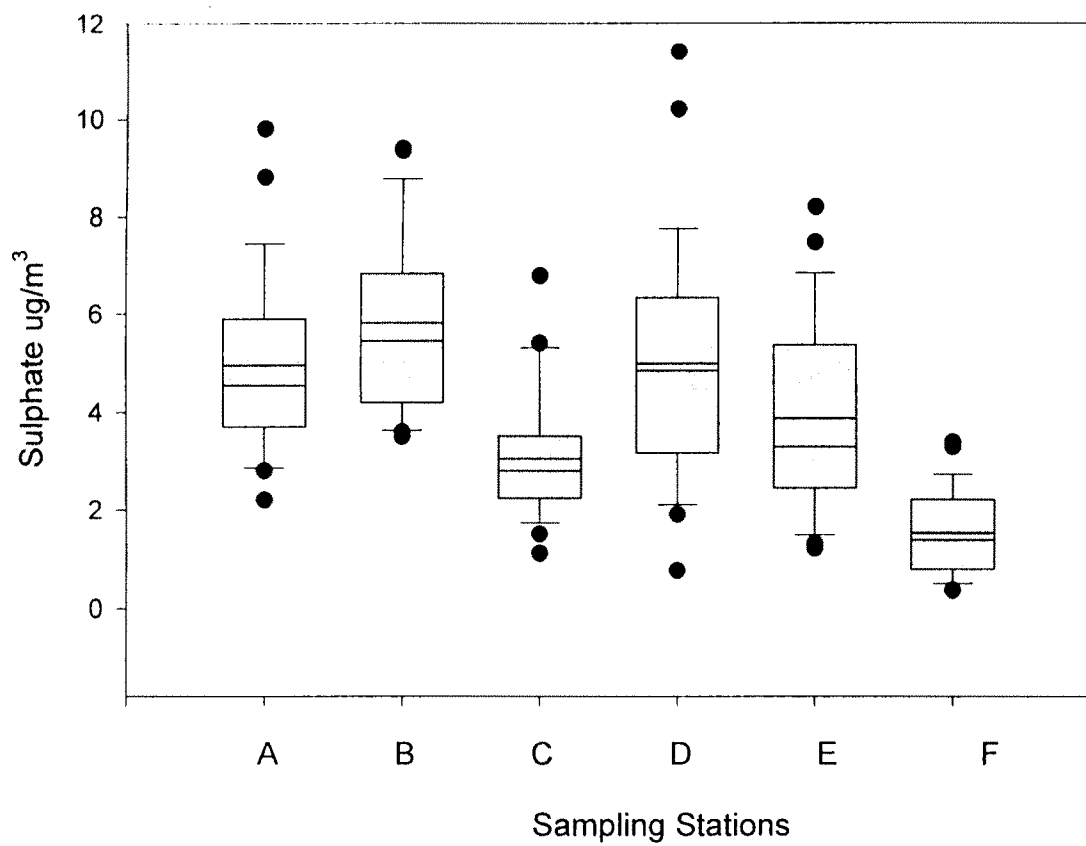


Figure 7.1 Sulphate in Sampling Stations A – F (for details on the figure refer the legend for Figure 5.1, Page # 69)

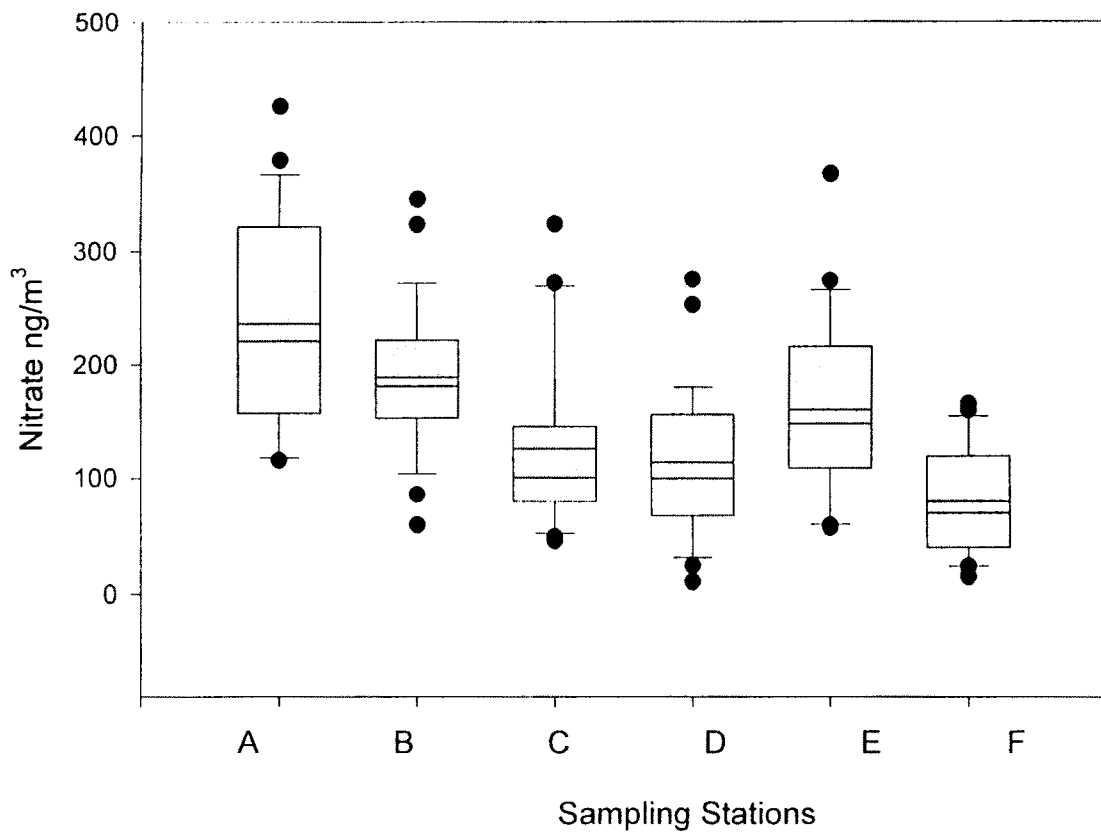


Figure 7.2 Nitrate in sampling stations A – F (for details on the figure refer the legend for Figure 5.1, Page # 69)

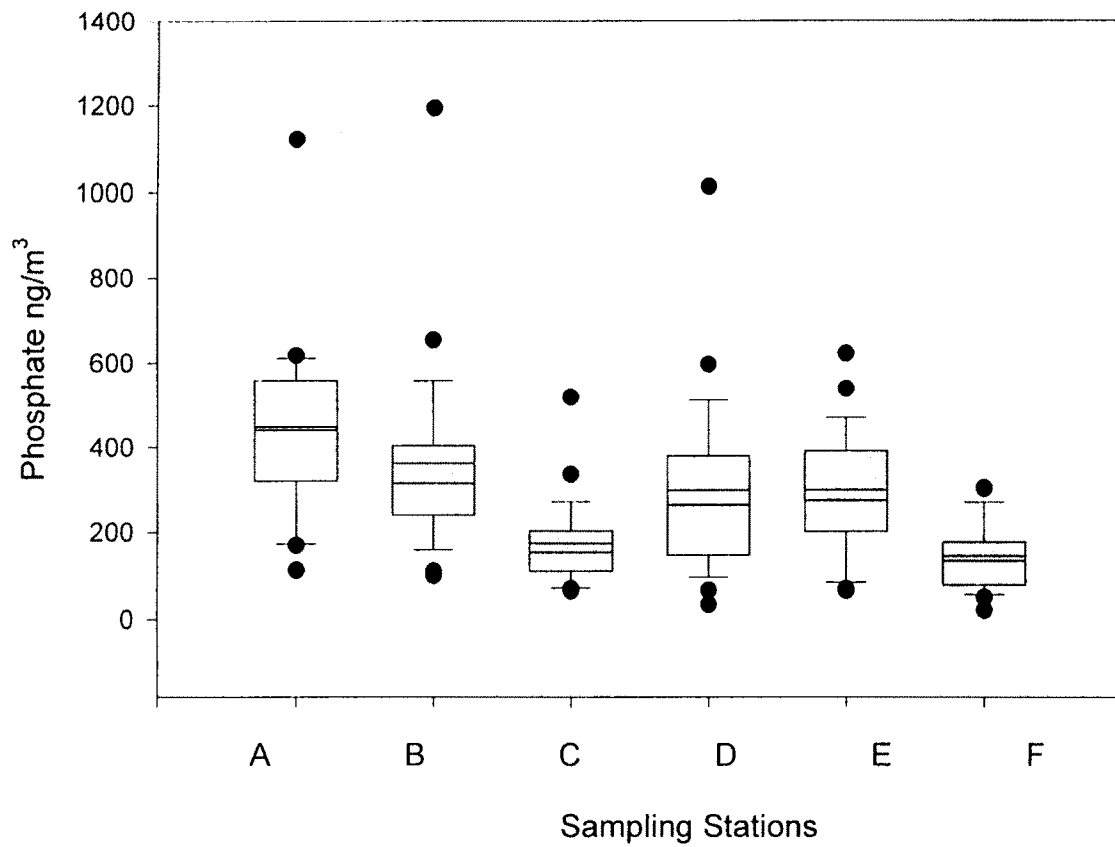


Figure 7.3 Phosphate in sampling stations A – F (for details on the figure refer the legend for Figure 5.1, Page # 69)

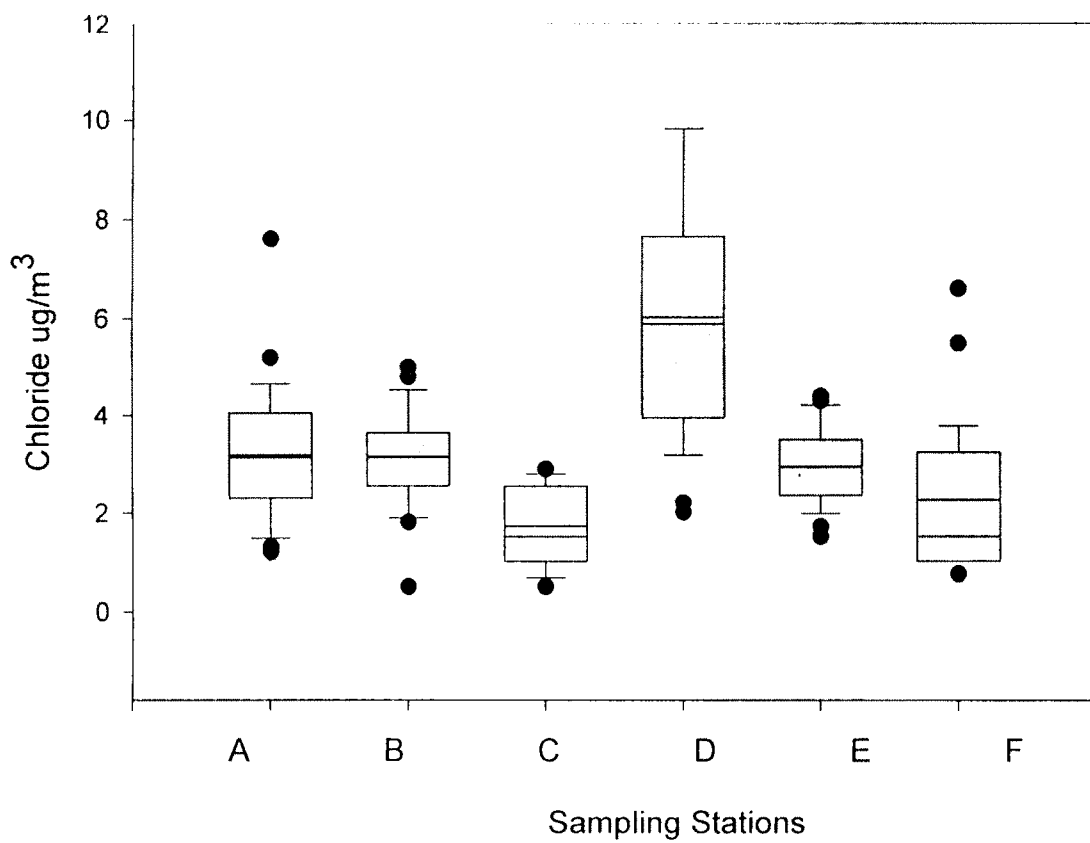


Figure 7.4 Chloride in sampling stations A – F (for details on the figure refer the legend for Figure 5.1, Page # 69)

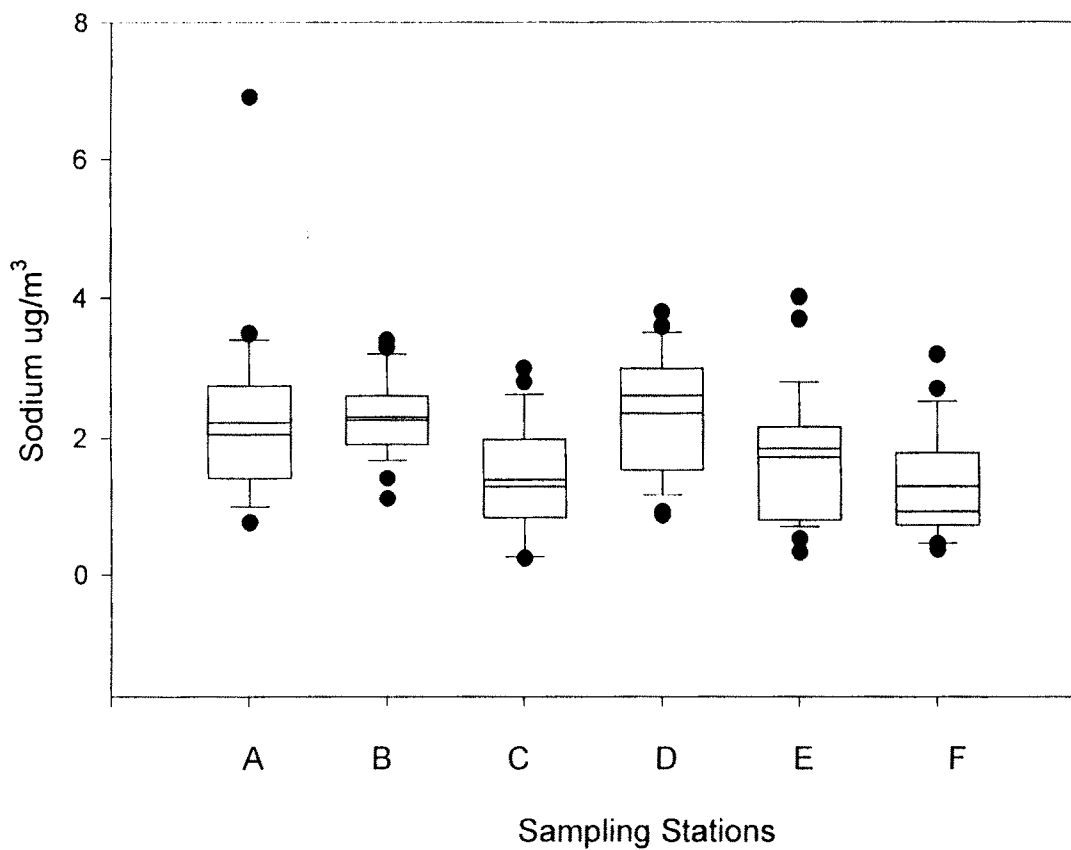


Figure 7.5 Sodium in sampling stations A – F (for details on the figure refer the legend for Figure 5.1, Page # 69)

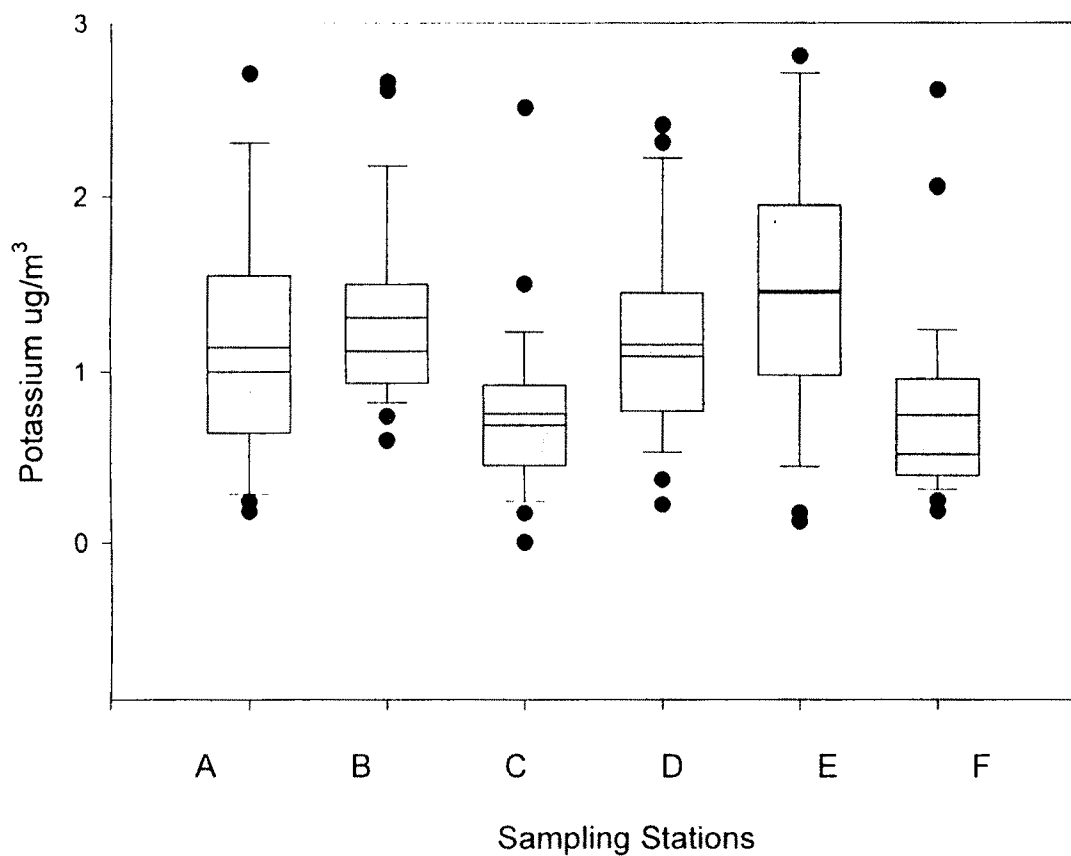


Figure 7.6 Potassium in sampling stations A – F (for details on the figure refer the legend for Figure 5.1, Page # 69)

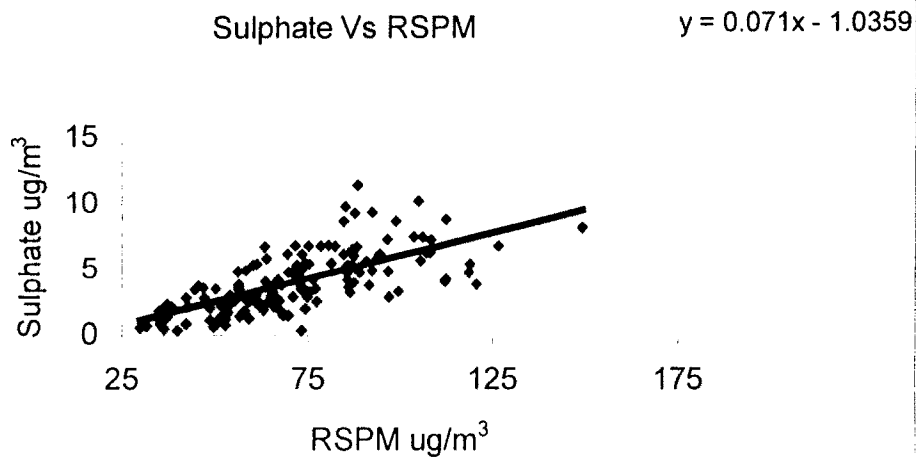


Figure 7.7 Linear regression between RSPM and Sulphate

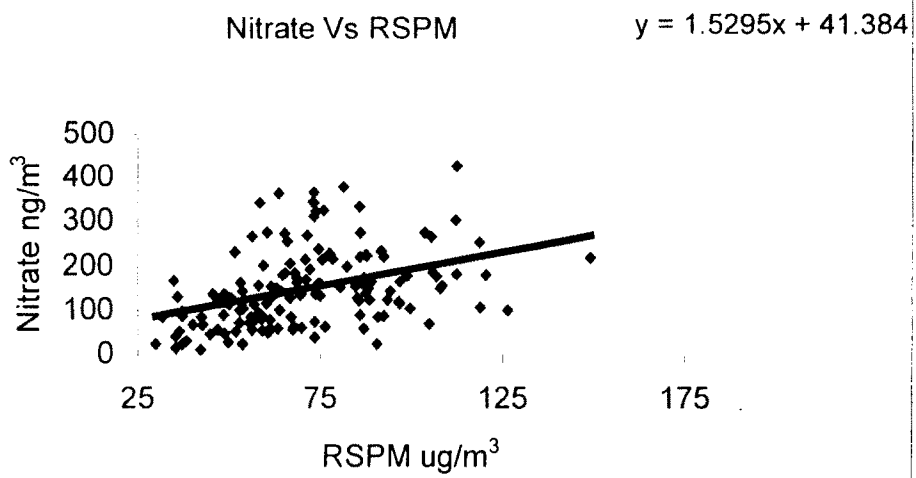


Figure 7.8 Linear regression between Nitrate and RSPM

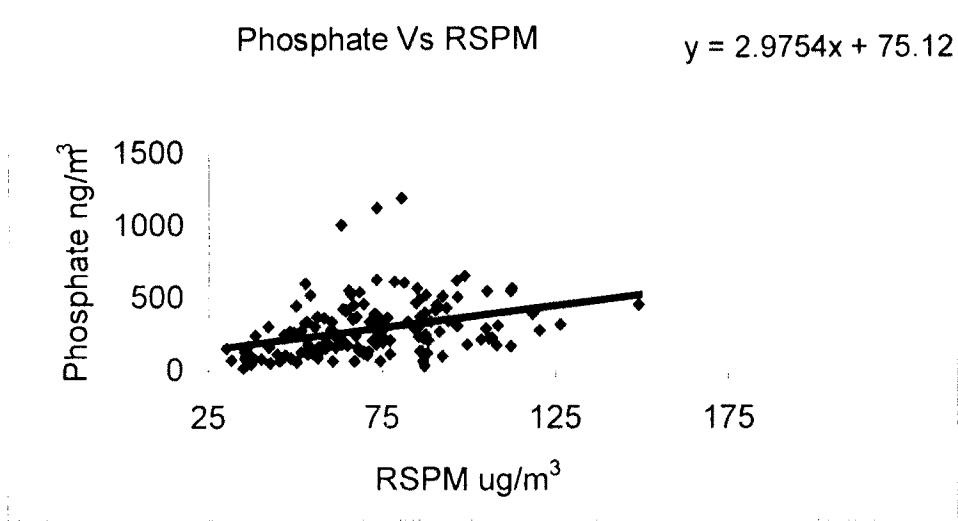


Figure 7.9 Linear regression between phosphate and RSPM

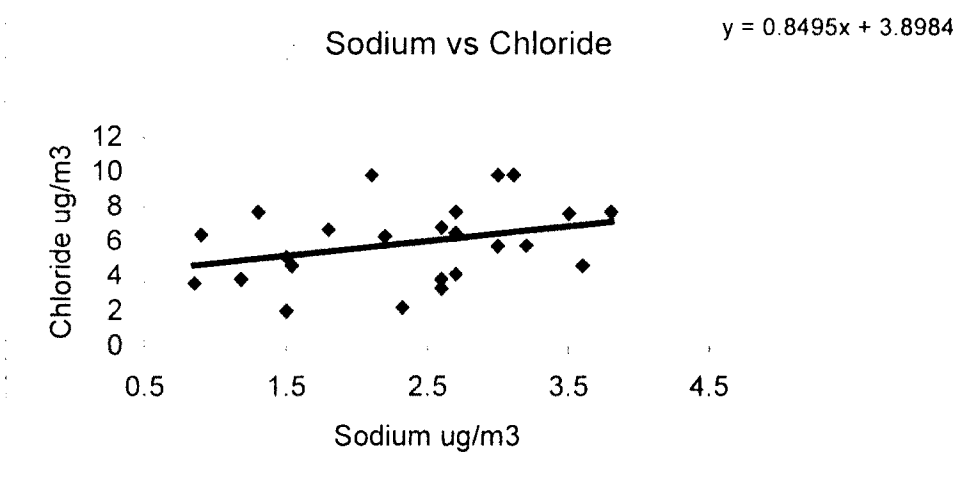


Figure 7.10 Linear regression between chloride and sodium

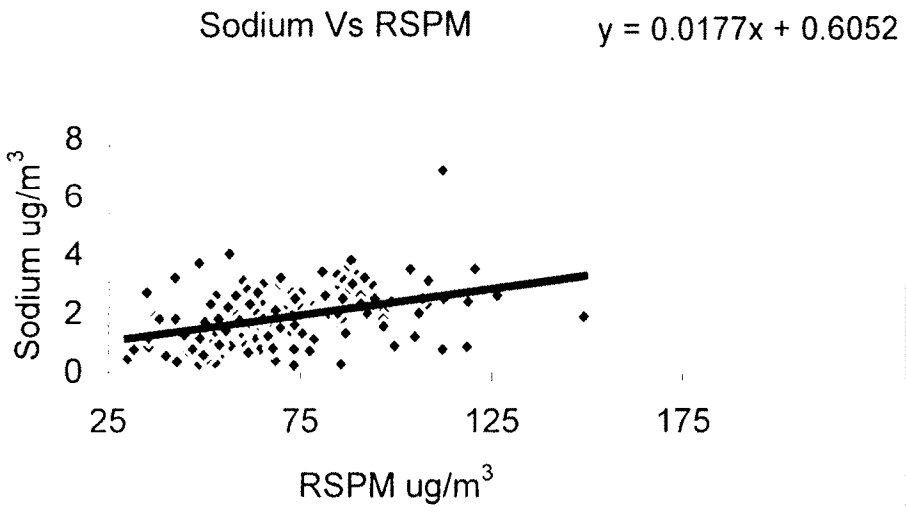


Figure 7.11 Linear regression between sodium and RSPM

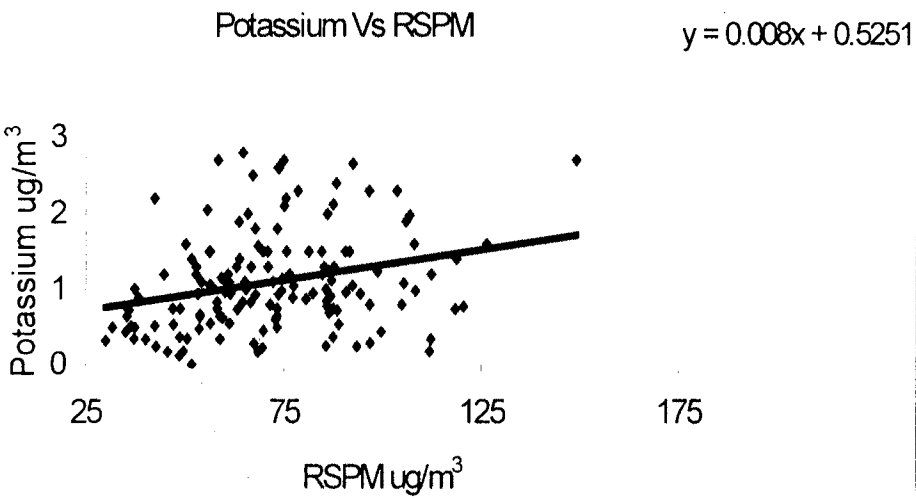


Figure 7.12 Linear regression between potassium and RSPM

7.5 Discussion

In the current study water soluble cations and anions constitute an average of about 13% of RSPM fraction (SO_4 , NO_3 , PO_4 , Cl, K, Na). Many studies have reported inorganic constituents comprising more than 30% of the airborne particulate matter (Ali-Mohamed 1991, EPA 1996). Except chloride, all other anions and cations having positive relation with RSPM suggests that majority of them have similar source (Figures 7.7 – 7.12).

The station wise mean sulphate abundance was in the order: B > D > A > E > C > F (Urban/Industrial > Residential/Rural) indicating anthropogenic urban activities as possible source for sulphate. Overall sulphate values irrespective of sampling stations showed high positive relation with RSPM values (Table 7.3, Figure 7.7). It may suggest influence of anthropogenic source such as gas to particle conversion. The fugitive dust derived from soil being an important contributor also cannot be neglected. Mean sulphate concentration in Coimbatore during the study ($4.03 \mu\text{g}/\text{m}^3$) did not exceed US EPA standard ($25 \mu\text{g}/\text{m}^3$ for permissible total particulate sulphate).

Sulphate was observed as dominant compound among the estimated inorganic constituents. Many studies have reported sulphate as major constituent of particulate matter (Cheng et al 1998, Wrobel et al 2000). Borbely-Kiss et al (1991) in an analysis of elemental composition of aerosol particles in Hungary found that silicon and sulphur in highest concentrations suggesting that it is partly of anthropogenic and partly of soil origin. A recent study by Rao et al (2001) in Pune, India also found SO_4 ion dominating the anion concentrations in TSPM. Nair et al (2001) reported sulphates in the range of $0.4 - 7.2 \mu\text{g}/\text{m}^3$ in SPM collected over the marine atmosphere of Arabian Sea mass, contributing ~13% of TSPM.

The presence of increased concentrations of ions such as SO₄ and NO₃ in polluted aerosols may influence natural process of nucleation. Sulfate, a major inorganic constituent can affect the regional and global climates by scattering radiation directly and indirectly by altering scattering characteristics of clouds. Direct radiative forcing is estimated to be -0.4 Wm^{-2} (IPCC, 2001). Penner et al (In Press) in a model study found that the direct forcing by anthropogenic sulfate aerosols can decrease from -0.81 Wm^{-2} to -0.53 Wm^{-2} if grid box average relative humidity is not allowed to increase above 90%. According to WHO recent estimates, sulfates in air are a major causative factor for increasing hospital admissions and even mortality. An increase of $10 \mu\text{g}/\text{m}^3$ of sulphates can cause increase in hospital admissions and daily mortality to be as high as 50 – 60%.

Hext et al (1999) while reviewing health effects of particulate matter found that acidic aerosols probably pose the greater risk to health especially respiratory disorders. However they also noted that there is no effect on pulmonary function in normal healthy individuals at concentrations of acidic aerosols as high as $1000 \mu\text{g}/\text{m}^3$. Sulfate is linked with premature mortality, respiratory hospitalization, and lung cancer and allergy exacerbation (<http://www.giss.nasa.gov/meetings/pollution02/>). Short-term PM and/or sulfate exposures to children are associated with reduced pulmonary function and increased respiratory symptoms in asthmatics (e.g., asthma attacks) and non-asthmatics (Thurston 2000). Long-term chronic PM and/or sulfate exposures to children are associated with reduced lung function, increased respiratory symptoms; and increased infant mortality, intrauterine growth reduction, or pre-term delivery.

Recently, declining trend of fine sulphate concentrations was observed by Christoforou et al (2000) in southern California. According to the study, during 1982, many cities

recorded sulfate concentrations in the range of 5.8 – 5.2 $\mu\text{g}/\text{m}^3$ annual average, while in the 1993 study, most of the same cities measured only 2.1 – 4.2 $\mu\text{g}/\text{m}^3$ of sulfate in the fine particulate matter. The change in the concentrations might be attributed to the improved diesel fuels that had been introduced to the vehicle fleet. Not much variation was found in nitrate and chloride content of the particulate matter with this change.

Higher chloride values obtained in station D (Industrial) may be due to the presence of foundries in the industrial estate using large quantity of sea sand for the casting process. The sea sand might be an important contributor to the RSPM here. Chlorides mostly appear to be derived from sea salt (Clarke et al 1999, Nair et al 2001) but occasional influence of road salt, especially in temperate areas, often noticed. Current study also hints that other sources such as soil resuspension might have contributed for chlorides. A positive correlation between sodium and chloride also probably suggests the same conclusion (Figure 7.10).

Average nitrate abundance in the current study ranging in order $A > B > E > C > D > F$ (Urban>Highway>Industrial>Suburban), indicates urban activities, followed by the highway and industrial activities as possible source for nitrate in RSPM. In the case of sodium, observed range in Coimbatore (0.23 – 6.9 $\mu\text{g}/\text{m}^3$) is higher compared to a recent estimation by Nair et al (2001), who reported sodium in the range of 0.25-3.7 $\mu\text{g}/\text{m}^3$ that is mainly of marine origin.

Higher potassium values (BDL – 2.8 $\mu\text{g}/\text{m}^3$) found in urban samples probably suggests that combustion sources and/or roadside dust due to traffic movement might be a major contributor. Kulshrestha et al (2001) over Indian Ocean north and south Inter Tropical

Convergence Zone (ITCZ), observed SPM bound potassium in the range of 0.07-1.43 $\mu\text{g}/\text{m}^3$, coming from some combustion process in the form of plume or K rich air masses.

7.6 Summary and Conclusion

Water soluble inorganic constituents namely sulphate, chloride, sodium, potassium, phosphate and nitrate in RSPM were analysed in RSPM in Coimbatore during March 1999 to February 2001. These water-soluble ions constitute an average of about 13% of RSPM fraction. Observed range of these ions were; sulphate = 0.35 – 11.4 $\mu\text{g}/\text{m}^3$, chloride = 0.5 – 9.8 $\mu\text{g}/\text{m}^3$, sodium = 0.23 – 6.9 $\mu\text{g}/\text{m}^3$, potassium = 0 (Below detectable limit) – 2.8 9 $\mu\text{g}/\text{m}^3$, phosphate = 20.5 – 1193 ng/m^3 and nitrate = 10.22 – 425.25 ng/m^3 .

Sulphate was observed as dominant compound among the estimated inorganic constituents. Except chloride, all other anions and cations having positive relation with RSPM suggesting that majority of them have similar source.

Comparatively higher chloride values obtained in station D (Industrial) suggests that presence of foundries in the industrial estate using large quantity of sea sand for the casting process might be the likely contributor of chloride.

CHAPTER – 8

Polycyclic Aromatic Hydrocarbons

8.1 Introduction

Urban aerosols contain wide array of organic constituents such as n-alkanes, n-alkanoic acids, n-alkanols and minor amounts of n-alkanedioic acids, n-alkanones, terpenoids and phthalate compounds (Simoneit 1999). Among these Polycyclic Aromatic Hydrocarbons (PAHs) is a large group of over 100 different chemicals with between 2 and 7 aromatic rings (Mumtaz and George 1995). Large quantities PAHs are released into environment by various human activities. Recently PAHs in the environment have claimed serious concern worldwide since the exposure to high concentrations is linked to carcinogenic or cocarcinogenic risk from air pollution (Kotzias and Brussol 1999a). More recently concern is expressed to their interference with hormone systems and their potential effects on reproduction, as well as their ability to depress immune function (Mumtaz and George 1995). PAHs are likely to have additive (synergistic) effects with other hydrocarbons mixtures and with other pollutants.

8.2 Background

8.2.1 Sources and concentrations of PAH in air across the world

PAHs are ubiquitous in the environment in urban as well as in rural areas. Earlier it was considered that PAH are formed only during high temperature (700°C) pyrolysis of organic materials. But the discovery of complex mixtures of PAH of wide molecular weight range in fossil fuels has shown that pyrolysis of organic materials even at low temperatures (100 – 150 °C) produces these compounds (Neff 1985). Microorganisms, higher plants and even few animals synthesize PAH. As the fossil fuels are the major source of energy, these group of organics in the environment has increased considerably

due to incomplete combustion of coal, oil and gas (Baum 1978, Moorcroft 1999). It is produced in all combustion process and burning of any organic material due to chemical recombination of organic radical intermediates produced by “cracking” of larger organic molecules (Larsen and Weber 1994). Burning of garbage and other organic substances like tobacco wood, medical wastes, rubber, cotton or charbroiled meat leads to PAH production (Levendis et al 2001, Nielsen et al 1992).

In the urban atmosphere the major source for PAHs are vehicular exhaust from gasoline and diesel powered engines, industrial process and waste incineration (Baek et al 1991, Menichini and Monfredini 1997). According to Hall (1999) nine defined sources of PAH include public (i) public power, (ii) commercial, institutional, residential combustion plant, (iii) industrial combustion plant, (iv) non-combustion process (e.g. Production of sulphuric acid), (v) extraction and distribution of fossil fuels, (vi) solvent use, (vii) road transport, (viii) other transport, (ix) waste treatment and disposal, (x) agriculture and (xi) nature. In indoor air, PAHs are mainly contributed by outdoor sources and burning of fuel (Dubowsky et al 1999).

During past two decades, benzo (a) pyrene a carcinogenic PAH compound was selected for analysis as a marker of general trend of PAH levels. In London during 1949 to 1951, an annual average concentration of 49 ng/m^3 benzo(a)pyrene was recorded. Introduction of innovative technologies in automobiles had reduced the emission levels. After (1993) with mandatory introduction of catalytic converters, for automobiles, a drastic reduction in its concentration 1.1 ng/m^3 was reported. Emission of PAHs such as fluoranthene, pyrene, chrysene, benzo(b/k)fluoranthene, benzo(a)pyrene, benzo(e)pyrene and benzo(e)perelyene are higher for diesel engines than gasoline engines. Gasoline engines with catalyst record further lower values. Decline of PAHs concentrations were reported

in many European countries after innovations in automobile technologies. Country wise detailed data on PAH concentrations as well as its decreasing trend is available in a report on state of art PAHs in ambient air compiled by Ballesta et al (1999). Certain other discussion on trend of air borne PAHs in various countries is shown Table 8.1.

Table 8.1 PAH concentrations in ambient air across the world

Location of the study	Range/Mean of PAH	Observations	Author
Germany	Benzo(a)pyrene (BaP) showed annual means between 0.7 and 3.5 ng/m ³	PAH concentrations showed seasonal fluctuation with higher values in winter and lower values in summer. Seasonal differences are higher than urban-local differences.	Beck (1999a), Beck (1999b) Beck (1999c)
Spain	Annual PAHs means in four cities varied between 0.2 – 71.9 ng/m ³ .	Values recorded in winter and autumn higher than summer and spring.	Bomboi et al (1999)
Bayreuth	Concentration of 10 PAHs ranged between 0.42 to 13190 pg/m ³ .	Changes in particle size distribution of particle mass were reflected in the particle size distributions of PAHs.	Kaupp and McLahen (1999)
Isfahan, Iran	A group 16 PAHs in atmosphere ranged between 0.25 – 3.02 ng/m ³ . Naphthalene and pyrene lowest and highest respectively.	Good agreement was found between the variation in concentration of PAHs and organic carbon, but not between TSP and PAHs.	Talebi (1998)
Rural northwest England	Mean concentrations of 9 PAHs was 12.3 ng/m ³		Lee et al (1998)
Greece	-	PAHs significantly correlated with vehicular pollutants in warm months and residential heating in cold months.	Papageorgopoulou et al (1999)
Thessaloniki, Greece	PAH concentrations between 2.1 – 8.5 ng/m ³ .	During Sundays PAH concentrations were lower than on weekdays. The main sources of PAHs were the stationary sources in winter and the traffic in summer.	Viras et al (1991)

Italy	55 ng/m ³ of BaP and total PAH were recorded respectively. Mean concentrations 10 PAHs during the year 1986-1997 range from 0.3 – 3.6 ng/m ³ .	differences of PAH levels was observed. Large differences in total PAH levels recorded in several towns and metropolitan areas.	(1999)
Rural and urban sites in Hong Kong	PAHs associated with TSP ranged between 0.41 – 48 ng/m ³ .	Benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(e)pyrene, indeno(1,2,3-cd)pyrene and benzo(ghi)perylene were dominant species in the samples. Vehicular emission was found as the major source of PAHs.	Zeng and Fang (2000)
Chicago, USA	Average total (gas + particulate) of 14 PAH concentration was 428±240 ng/m ³ .	The amount of particle phase PAHs increased with decreasing temperature.	Odabasi et al (1999)
Naples, Italy	Total PAH were in the range 2-130 ng/m ³	Seasonal variation in the range 1.5 - 4.5 ng/m ³ .	Caricchia et al (1999)
Finland	Total PAHs (31 compounds) ranged from 20 ng/m ³ in Ahtari to 1531 ng/m ³ in Helsinki in winter.	Scavenging effects of rain and snow is clearly observed. Current PAH levels lower than 1993 levels.	Sandell et al (1999)
Belgium	Total 8 PAHs concentrations in winter 13.73 ng/m ³ and summer 5.22 ng/m ³ at street canyon, while it varied between 1.72 ng/m ³ to 9.17 ng/m ³ in residential and other areas.	The most important permanent source was motor traffic. Domestic heating another important source.	Wauters and Lenelle (1999)
Vienna, Austria	Benz(a)pyrene ranged between 2 –7 ng/m ³ (Mean = 4.2 ng/m ³)	Naphthalene can be lost substantially during sample preparation.	Gans (1999)
Tropical and temperate urban environments of Asia and Australia	Total of 20 PAHs range (ng/m ³) in different places were: Jakarta = 13.3 – 177 ng/m ³ , Bangkok = 4.97– 74, Seoul = 7.7 – 265, Hong Kong = 2.6 –28.1, Melbourne = 1.68 – 21.53.	In temperate cities of Melbourne and Seoul, PAH concentrations were higher cold winter and lower during the warm summer. In tropical region higher and lower PAH concentrations were observed during dry and wet season respectively.	Panther et al (1999)
Urban Delhi,	BaP range 4.99 – 9.56 ng/m ³	-	Banerjee and Khillare (1986)

Urban Delhi, India	BaP range 4.99 – 9.56 ng/m ³	-	Banerjee and Khillare (1986)
Nagpur, India	Total average concentration of 4 PAHs (ng/m ³) in respirable fraction were: Fluoranthene: 0.7, Pyrene: 14.9, Benzo(a)anthracene : 24.5, Benzo(b) fluoranthene: 57, Benzo(a) pyrene: 27.1.	70% of PAHs are concentrated in respirable fraction.	Vaishali et al (1997)
Calcutta, India	The lowest and highest sum of 12 PAHs was 22.91 and 190.96 ng/m ³ at Jadavpur and Maulali respectively in 1994. The average BaP concentration was 10.4±4.76 ng/m ³ .	-	Chattopadhyay et al (1998)

8.2.2 Properties and fate of PAHs

PAHs in atmosphere are present in both vapor and particle phase (Chuang and Battelle 1999, Moorcroft 1999, Hall 1999). During their transport in atmosphere PAHs may undergo chemical and photochemical reactions probably resulting often in compounds that are more toxic than the parent compounds (Kotzias and Brussol 1999b, Hall 1999). Most PAHs on reaction with air, sunlight and other pollutants (e.g., O₃, NO_x and SO₂) in the atmosphere form PAH derivatives such as nitro-PAHs and oxygenated derivatives (Chuang 1999). PAHs in particle phase are converted to highly mutagenic nitrated compounds, when irradiated in the presence of nitrogenous air pollutants. The behavior of PAHs in environment is greatly affected by its source. PAHs derived from oil and non-combusted petroleum products differ from those on combustion particles. The speciation of PAH that differs with its source ultimately determines their transport, fate and bioavailability in the environment (Naes et al 1998).

Most PAHs do not dissolve easily in water. Some PAHs readily evaporate into the air. PAHs generally do not burn easily and will last in the environment for months to years (Mumtaz and George 1995). They travel long distances before returning to earth in rainfall or particle settling. Deposition of PAHs is also detected at short distance in roadside environment (Benfenati et al 1992). Halsall et al (2001), in a modeling study opined that reaction with OH[•] radicals was a major removal mechanism of for gas phase fluoranthene and phenanthrene, and wet deposition in the form of snow accounted for majority of PAH removal from the atmosphere in winter.

8.2.3 PAH exposure and absorption in humans

Human exposure to PAH can occur through several environmental pathways. Inhalation exposure is a most significant route of exposure for people living in and around urban areas and hazardous waste sites. Drinking water or food, soil, or dust particles carrying PAHs are other routes for these chemicals to the body (Mumtaz and George 1995). PAHs could also enter the body via skin on contact with soil that contains high levels (this could occur near a hazardous waste site) or with heavy oils or other products (such as coal tar, roofing tar, or creosote) that contain PAHs. PAHs enter the body quickly and easily by all routes of exposure. The rate of PAHs entering the body increases when they are present in oily mixtures. They go to all tissues containing fat, and tend to be stored mostly in kidneys, liver, and fat, with smaller amounts in spleen, adrenal glands, and ovaries. Results from animal studies show that PAHs do not tend to get stored in the body for long time. Most PAHs leave within a few days, primarily in the feces and urine.

8.2.4 Toxicity and health effects

Inhalation exposures of PAHs are known to cause a variety of health disorders (Mumtaz and George 1995). Although no studies report PAH associated death in humans, a dose

related decrease in survival was noted after 60 weeks of inhalation exposure to 46.5 mg/m³ of benzo(a)pyrene for 109 weeks. An investigation on workers in rubber factory in association with background levels of SPM and benzo(a)pyrene exhibited significant disorders such as radiographic abnormalities including patch opacities, pleural effusions, bloody vomit, breathing problems, chest irritation, chest pains, throat irritation and cough.

A Study in Poland showed that coke-oven workers, exposed to high concentrations of atmospheric PAHs including fluoranthene, perylene, benzo(a)pyrene, benzo(a)anthracene, dibenz(a,h)anthracene Benzo(ghi)pyrene, chrysene had reduced levels of serum immunoglobulins. In China high lung cancer rate was associated with the smoky coal (Mumtaz and George 1995). Positive results of PAH-DNA adducts in placentas from women burning coal without chimney are also known. The fluorescent color assay found a significant association between PAH-DNA adducts detection in placenta and cooking method (coal with chimney, coal without chimney, natural gas). Another study showed that newborns with elevated PAH-DNA adducts had significantly decreased birth weight ($p \leq 0.05$), birth length ($p \leq 0.02$), and head circumference ($p \leq 0.0005$). Some PAHs are known immunosuppressants, teratogenic, embryotoxic, and mutagenic (Kuo et al 1998, Levin et al 1978). Reports also indicated that dinitropyrenes are responsible for most of the direct acting mutagenicity of urban airborne particulate in major cities of Taiwan (Chou and Lee 1990).

PAHs, both vapor as well as particle bound act as genotoxic carcinogens. Irrespective of their individual physical properties, they are capable of damaging genetic materials and there by initiating development of cancers (Moorcroft 1999). Mutagenic and carcinogenic property of PAHs are linked with its physical properties such as electronegativity or K- or L-region reactivity indexes, electrophilic potency, dipole moment, intramolecular and

subcellular binding, hydrophobicity and others (Cavander 1994). The following 15 PAHs are considered as a group of priority pollutants by US Environmental Protection Agency (US EPA): Acenaphthene, acenaphthylene, anthracene, benz(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(ghi)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-cd)pyrene, phenanthrene, and pyrene. The International Agency for Research on Cancer (IARC) has classified 48 PAH compounds likely to be carcinogenic to humans. Of which benzo(a)pyrene, benzo(a)anthracene, dibenz(a,h)anthracene are some of the probable carcinogens and benzo(b)fluoranthene, benzo(k)fluoranthene, indeno(1,2,3cd)pyrene possible carcinogens. The Department of Health and Human Services (USA) has determined that benzo(a)anthracene, benzo(b)fluoranthene, benzo(j)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene indeno(1,2,3cd)pyrene as possible carcinogens.

Recently a nitrated PAH compound 3-Nitrobenzanthrone (Figure 8.1), discovered from the exhaust fumes of diesel engines, is suspected to be the strong and worst ever carcinogenic compound (Pearce 1997). In a test with a strain of *Salmonella typhimurium*, 3-nitrobenzanthrone recorded more than 6 million mutations per nanomole, which is considerably higher than the previous known most mutagenic compound 1,8-dinitro pyrene (also found in diesel) that recorded 4.8 million mutations per nanomole. 3-nitrobenzanthrone also is found to cause chromosomal aberrations in blood cells of mice. Researchers feel that this compound could be a major culprit responsible for lung cancer in urban areas.

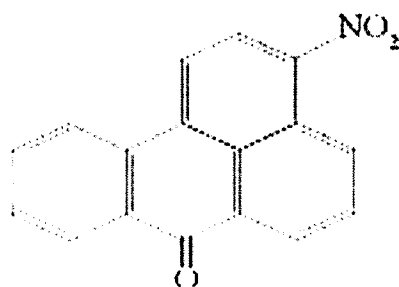


Figure 8.1 3-nitrobenzanthrone

8.3 Materials and methods

The respirable fraction (RSPM or PM 10) of the suspended particulate matter is collected on a preweighed Whatman glass microfibre filter paper (GF/A 20.3 x 25.4 cm) at six sampling stations mentioned in chapter 2 (A,B,C,D,E and F) using high volume air sampler (airflow rate of 0.9 to 1.2 m³/min) during March 2001. The sampling time was 24 hours. At each station 2 samples were collected. The glass fibre filter carrying RSPM, were cut into small pieces. Equal proportion of the 2 samples from each station is mixed and taken for PAH estimation.

Several analytical techniques have been used to determine the particle bound PAH in gas chromatography. For the current study prior to the analysis of PAH, suggestions from earlier studies (Ballesta et al 1999, Banerjee and Khillare 1986, Chauang and Battelle 1999, Matsushita 1978, Menichini and Monfredini 1997, Patnaik 1997, Pinciro-Ilesias et al 2000) were considered. Soxhlet extraction of filters carrying RSPM in benzene was performed for 12 hours. The sample extract was then purified in a silica gel column chromatography and then extract was evaporated to small volume (2-3 ml) in a rotating evaporator (under reduced pressure and a water bath temperature of 40°C). An aliquot of

0.5 µl was analysed by Gas Chromatography (Model Shimadzu 15A) with flame ionization detector. A fused silica capillary column with methyl silicone (SPB 5: length 30 meters, ID 0.25mm) was used. The temperature programme followed is as follows: 80°C/5min, 10°C/min to a final hold at 280°C -25 min until all peaks have eluted. Carrier gas was nitrogen (1ml/min). Quantification of PAH was performed using a standard PAH mix (Mixture of 13 compounds - SUPELCO) run under similar conditions.

8.4 Results

The levels RSPM bound PAHs (13 compounds) found at six sampling stations are shown in Table 8.2. Sampling station B (Gandhipuram) is found with highest PAH concentration (172.28 ng/m³), while the lowest was recorded in Station F (20.5 ng/m³). Among the PAH compounds naphthalene was the dominant compound. An example Chromatogram of sample B is shown in Figure 8.2. A significant positive association between RSPM and total PAH was found (Figure 8.3).

Table 8.2 PAH Concentrations in Sampling Stations

PAH Compounds (ng/m ³)	Sampling Stations					
	A	B	C	D	E	F
Naphthalene	35.6	50.12	15.9	33.3	43.7	12.65
Acenaphthylene	5.9	BDL	3.6	12.6	9.06	BDL
2-Bromonaphthalene	BDL	8.21	BDL	4.3	BDL	BDL
Acenaphthene	3.45	1.25	BDL	5.3	6.9	2.8
Fluorene	15.87	31.3	6.6	15.63	BDL	BDL
Phenanthrene	20.14	33.7	BDL	21.3	15.6	BDL
Anthracene	8.7	14.6	BDL	7.31	17.5	4.6
Fluranthene	12.4	9.9	1.7	BDL	BDL	BDL
Pyrene	5.8	20.1	BDL	10.64	6.7	BDL
Benzo(a)anthracene	BDL	3.1	BDL	1.8	2.6	BDL
Chrysene	BDL	BDL	BDL	BDL	BDL	BDL
Benzo(b)fluoranthene	BDL	BDL	BDL	BDL	BDL	BDL
Benzo(a)pyrene	BDL	BDL	BDL	BDL	BDL	BDL

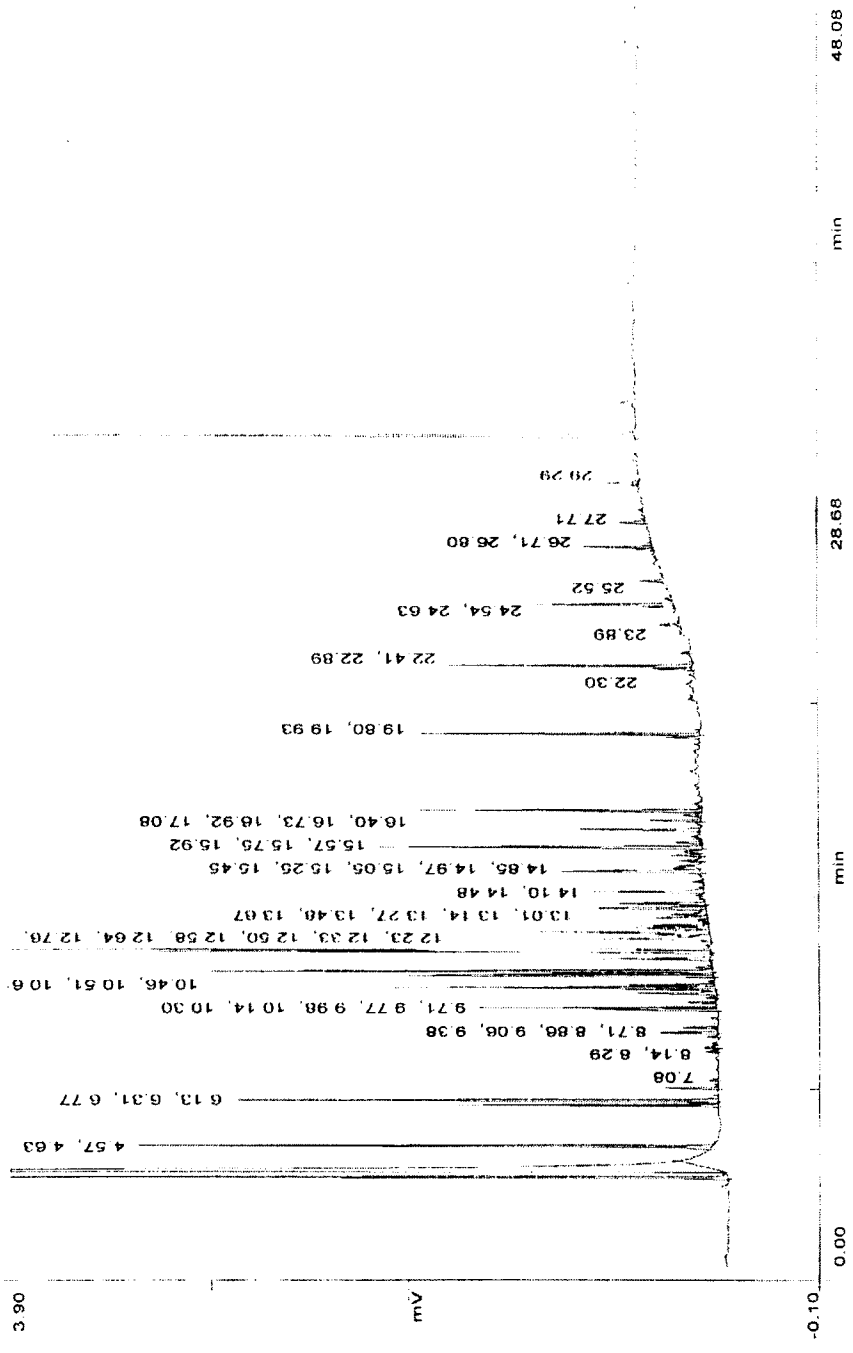


Figure 8.2 Chromatogram of sample

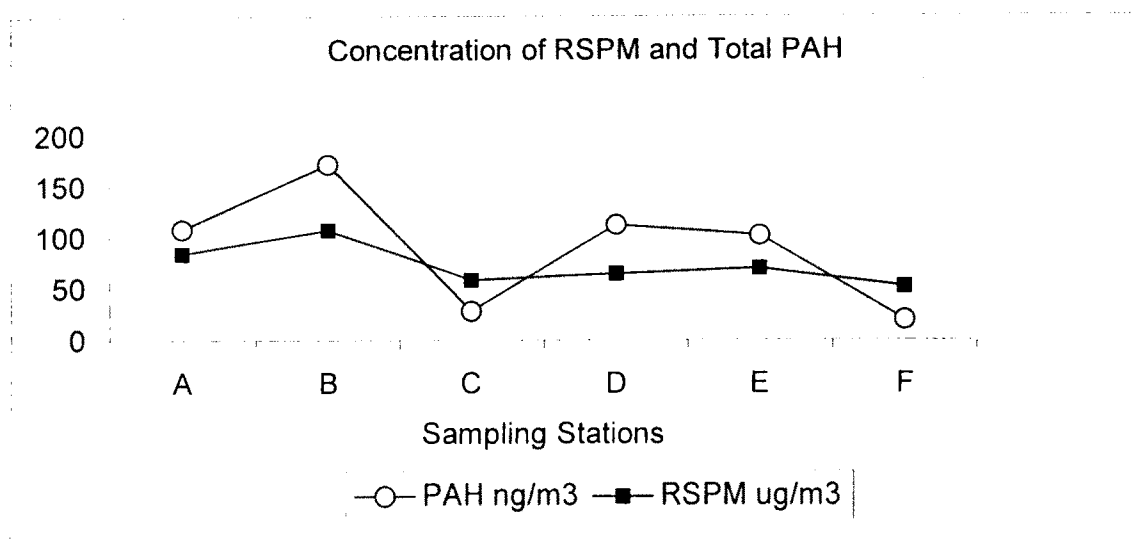


Figure 8.3 Total PAH concentration and corresponding RSPM in sampling stations

8.5 Discussion

Urban samples (Station A, B) and samples of industrial area and motor ways (Station D, E) are found with higher PAH concentration than the suburban/rural sample (station F), indicating traffic and industrial sources their major source. In the current study, naphthalene was observed high in samples (15.9 – 50.12 ng/m³). Studies had shown that half or up to 2/3 of naphthalene was lost if the sampling time was increased to 48 to 76 hours (Chauang 1999). Earlier studies also found naphthalene as most abundant PAH in air (Chauang 1999, Chauang and Battelle 1999). Generally PAH concentrations decreases as its ring size of the PAH increases.

Average of concentrations of pyrene (7.2 ng/m³) is more or less equivalent to the levels observed in earlier studies at Nagpur and Calcutta, India (Vaishali et al 1997, Samanta et al 1998). Anthracene and phenanthrene observed in Coimbatore samples were higher compared to the levels reported in Calcutta (Samanta et al 1998). Certain other PAH compounds chrysene, benzo(b)fluoranthene and benzo(a)pyrene that were below

detectable limits in Coimbatore were reported in substantial quantities in earlier studies (Vaishali et al 1997, Samanta et al 1998, Chattopadhyay et al 1998, Banerjee and Khillare 1986).

Total air sampled, sampler flow rate and sampling time, sample extract matrix and final volume, clean-up steps and instrument detection sensitivity are important factors affecting the PAH detection limits (Chauang 1999). According to Ballesta (1999) there is no agreed universal procedure for sampling and analysis of PAHs in atmosphere. The most common procedure for extraction of PAHs from airborne particulates is the soxhlet extraction with organic solvents of low to medium polarity. However this method has disadvantages such as long extraction period and large amounts of solvents. Usually when particle was collected on glass fibre filter, ultrasonic or soxhlet extraction using solvents such as hexane/cyclohexane, dichloromethane, benzene or toluene is adopted. Manoli and Samara (1995) suggested that ultrasonic extraction using acetonitril had high recovery rates for many PAHs.

According to Beck (1999) selection of PAH compounds, measurement strategies vary from state to state and in addition there is no common satisfactory assessment procedure. The current study suggests further experimentation for Coimbatore environmental conditions, on air sampling time, sample flow rate for PAHs, selection of solvents for extraction, extraction time and method, storage time of extracts, and instrumental method for analysis (HPLC/GC). In the current study, another sample replicate extracted with cyclohexane, cleaned with silica gel and analysed in GC/FID resulted many PAHs as below detection range. Hence to determine the accurate concentration of PAH a reference analytical method has to be developed and standardized according to the local

environmental condition. However, current study could not carry out this experimentation due to time and resource constraints.

In India except very few studies (Table 8.1) monitoring and assessment of PAH is rarely done. The Central Pollution Control Board had recently initiated regular monitoring of PAHs in ambient air in select cities. However the trends had been not yet published. Even in the current standards and specification for diesel engines there is no emission limit for PAH. But the Mukhopadhyay committee had specified 10% of PAH by weight as limit that should confirm by 2005 (Down to Earth 2001b).

8.6 Summary and conclusion

A total of 13 PAH compounds were analyzed in RSPM samples collected on glass fibre filters from six sampling stations mentioned in the study area. To determine PAH, RSPM collected in glass fibre filters were extracted in benzene, cleaned up using silica gel column and analysed in GC/FID. Total PAHs (13 compounds) in samples ranged between 20 – 172 ng/m³ with an average 90.37 ± 57.4 ng/m³. Samples of urban and industrial area are found with higher PAH concentration than the suburban/rural sample, indicating traffic and industrial sources as a major anthropogenic source for PAH. In the current study, naphthalene was observed highest in concentration in samples (15.9 – 50.12 ng/m³).

CHAPTER – 9

Respiratory Health Status

9.1 Introduction

World Health Organization (WHO) defines health as a state of complete physical, mental and social wellbeing and not merely the absence of disease or deformity or infirmity. Among the variety of factors influencing healthy state of an individual, the natural elements (the air we breathe, the water we drink, the radiation we are exposed etc.) and the man made environmental modifications (habitat, place of work, transport, industry and other development activities) play an indispensable role. Chemical agents such as emissions from industries and automobiles, effluents arising out of domestic and industrial activities and pathogenic agents impact the human health seriously. The respiratory system is one major route where by the chemical and pathogenic agents find entry into the body and cause disorders including mortality. On a global scale millions suffer from respiratory ailments and other diseases attributed to the presence of toxic chemicals and biological agents in the environment (WHO 2002).

Concentration of any pollutant in environment is a quantitative expression of the presence of pollutant, but there is no exposure unless there is physical contact with the human being (Janssen 1998). Exposure denotes to the event when the person comes into contact with a pollutant for a particular time. On the other hand dose refers to the actual quantity of pollutant that crosses the barrier of a body. These factors are important especially in determining relationship between air pollutants and health effects in human beings.

9.2 Background

9.2.1 Inhalation exposure and deposition mechanism

SPM, a major atmospheric pollutant, is recently given emphasis world wide for its adverse health effects. SPM that has an aerodynamic diameter below 10 microns (PM 10) is the respirable fraction that penetrates the respiratory system. Fine particulate matter with an aerodynamic diameter of below 2.5 microns (PM 2.5), on inhalation penetrates up to the alveoli and obstruct gas exchange process of respiration. The particles of size range 4.6 – 9 μ m normally deposits in the region of tracheo-pharynx, 1.1-4.6 μ m; bronchi and 0-1.1 μ m; alveoli (Figure 9.1).

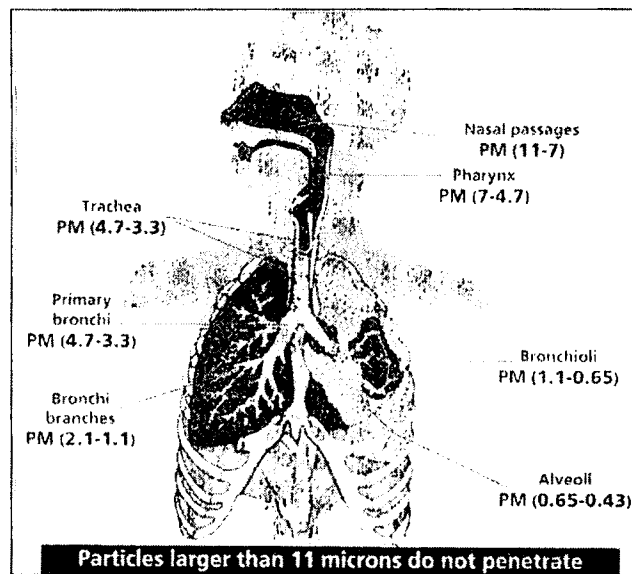


Figure 9.1. Penetration pattern of RSPM (Source: Down to earth (1999d) – after Wilson and Spengler (1996))

Penetration of airborne particulate matter into the lung airways is determined primarily by convective flow, i.e., the motion of the air in which particles are suspended (Lippmann 1992). Particles deposit within the respiratory tract by five mechanisms (1) inertial impaction, (2) sedimentation, (3) diffusion, (4) electrostatic precipitation, and (5) interception. The particles <0.5 μ m is deposited in small air ways by diffusion, where it is

avored by the small size of the airways and the low flow velocities in such air ways. For particles 0.5 –2 μm , deposition occurs in small to midsized airways by sedimentation. For particles >2 μm particle inertia cause the particle motion to deviate from the flow stream lines, resulting in deposition by impaction on the surfaces of the downstream primarily in mid to large-sized airways. Interception is deposition by physical contact with airway surfaces. The interception potential of any particle depends on its physical size, and fibers are the chief concern in relation to the interception process. Their aerodynamic size is determined predominantly by their diameter, but their length is the factor that influences probability of interception deposition. Electrostatic precipitation is deposition related to particle charge.

Particles deposited inside the lungs are cleared by several mechanisms (Dockery and Pope III 1997). Particles deposited in the bronchi and bronchioles (ciliated air ways) are captured on the layer of the mucus lining and are carried out of the lungs on the mucociliary ladder for expulsion through coughing or its swallowed. Particles deposited deeper, in the nonciliated airways are engulfed by lung macrophages and cleared more slowly, as the macrophages transport the particles onto the mucociliary ladder or into the lymphatic system. According to Nikula et al (2001) in human beings, chronically inhaled particulate matter was retained mainly in interstitium of lungs (57 – 91%) and its percentage increases with increase in dose. Overall, clearance of insoluble particles deposited in the pulmonary region of the lung has half-times that are measured in weeks to months or even years (WHO 2000). Clearance mechanisms themselves may be adversely affected by inhaled toxicants, so that clearance may take even longer because of the influence of the particles and co-pollutants such as ozone. There are large differences between species in the clearance rates of particles from the lung. The clearance rates in

dogs and humans seem to be comparable, but clearance of a variety of particles from the lung of rats was shown to be much faster than from either humans or dogs. As a result, the long-term retention of particles deposited in the lung can be much greater in humans than in rats, with obvious consequences for the extrapolation of long-term inhalation studies in rats to humans.

Brauer et al (2001) in a study on retained particles in the lung examined the paranchymal particle content of 11 autopsy lungs from nonsmoking individuals of Mexico city (3 year mean of PM 10 = 66 $\mu\text{g}/\text{m}^3$) and 11 control residents of Vancouver, Canada (3 year mean PM10 = 14 $\mu\text{g}/\text{m}^3$). Mexico City lungs contained significantly higher particle concentrations.

9.2.2 Toxicity of particulate matter

Biological or symptomatic effects of the deposited particles are determined by the chemical nature of the particles, the site of deposition within the lungs and the physiologic response to the particles. Possible fine particulate components that may be responsible for observed health effects include PM 2.5 mass, particulate associated sulfate, nitrate, acidity, soot, transition metals, organic contaminants and total ultrafine particles. Organic carbon (OC) and elemental carbon (EC) are the major carbon fractions in the PM responsible for many deleterious health effects (Hamilton and Mansfield 1991). OC is suspected as mutagenic and carcinogenic, while EC is linked to adverse range of environmental effects including interference in the lung clearance mechanisms.

Generation of reactive oxygen radicals by the particles is suggested as an important factor for acute and chronic toxic effects in respiratory system. The PM 10 tested from diesel and gasoline exhaust particles, urban dusts generated hydroxyl radicals in aqueous

buffered solutions (Valavanidis et al 2000)

Houdt (1990) in a review of mutagenic property of air borne PM has stated that several PAH associated with PM turned out to be a direct acting mutagen while some others are indirectly acting mutagens in *Salmonella*/microsome assay. Other organic compounds such as nitroaromatics, pyrene 3,4-dicarboxylic acid anhydride, dimethyl and monoethyl sulphate, 20-carbonhalogen compounds and polycyclic ketones and quinones also showed mutagenic activity. People living in urban areas characterised by high levels of petrochemical pollution had apparently higher risk of developing lung cancer than people in the areas of low air pollution (Yang 1999).

Long et al (2001) in a study of assessment on in-vitro toxicity of in-door and out-door particulate matter, conducted bioassays using rat alveolar macrophages (AM) and tumor necrosis factor (TNF) to assess the particle induced pro-inflammatory responses. Significant TNF production was found above the negative controls in AMs exposed to either indoor or outdoor particulate matter.

Pulmonary diseases caused by air pollution may involve 3 target tissues (Gross 1961). These are (i) the respiratory passage (ii) blood vessels and (iii) respiratory membrane. The most prevalent pulmonary disorder is asthma in which the target tissue is the walls of bronchi and bronchioles. The proliferated alveolar cells may desquamate extensively there by producing a condition, which has been called desquamative or catarrhal pneumonia. The bronchial responses including bronchio constriction resulting in constriction of smooth muscle may occur in trachea and bronchi (Shukla and Srivastava 1992). In 1987 there were approximately 25 million individuals in US who had asthma. The illness associated with asthma accounted for 27 million patient visits and 470,000

hospital admissions annually (Koren and Utell 1997). The World Health Organization assessed that about 460,000 of people die each year because of SPM, of which 135,000 are victims of chronic asthma and rest die of cardio vascular or heart diseases (Patterson and Eatough 2000).

9.2.3 Health effects of SPM

As mentioned elsewhere, acute air pollution episodes such as London smog episodes (1952, 1962), the Donora smog (1948), Muese valley (1930) etc., (Faith and Atkission 1972) that resulted in heavy mortality clearly indicates that short term elevated levels of particulate matter and sulphur dioxide are associated with variety of pulmonary disorders including mortality. Since then whether such analogous health effects and mortality would occur from long-term exposure to low-level concentrations formed a hypothesis. Several epidemiological studies were attempted across the world and many revealed an association between suspended particulate matter and acute and chronic respiratory disorders, lung cancer, morbidity and mortality (Wichmann et al 2000, Pope III et al 2002, Lee and Schwartz 1999, Zee et al 1998, Dockery et al 1993, Dockery et al 1992, Dockery and Pope 1994, Spix et al 1993, Ortega-Rubio 1998, Lipfert 1997). Associations have been found not only with cardiovascular deaths but also with myocardial infarctions and ventricular fibrillation (Dockery 2001). Particulate matter is also associated with autonomic function of heart including increased heart rate, decreased heart rate variability and increased cardiac arrhythmias. The hypothesis was also strengthened by observations such as urban-rural differences in the case of mortality from lung cancer and chronic obstructive pulmonary disease. Although lung cancer was rare in the beginning of the 20th century, today it has become one of the leading causes of death in males of the industrialized world. Internationally, lung cancer accounts for up to 13% of all deaths above 45 years of age. The global incidence of lung cancer is increasing at a rate of 0.5%

a year. In china relatively elevated rates of adenocarcinoma of lung among women have been attributed to exposure of environmental pollutants and smoking tobacco.

Acute infections involving upper respiratory damage causing major morbidity was reported as early since late 1950's (Neill et al 1962). Neill observed that US national health survey reported 219 million workdays lost between July 1957, and June 1958 due to acute respiratory disease, including Asian influenza. Dohan (1960) reported the incidence rates of respiratory illness such as a) influenza, b) bronchitis, acute and chronic, c) pneumonia, all types d) asthma, e) sinusitis and other respiratory disorders of employees exposed to suspended particulate matter during 1955-1958 at five urban cities showing high degree of positive correlation with particulate bound sulphate. The study also found increased respiratory illness with increase in nickel and vanadium in four cities, while the values for air borne bismuth, cadmium, iron, lead, titanium and chloride showed no correlation with respiratory disorders. Following are few recent studies reporting association between particulate matter mortality and morbidity.

9.2.3.1 Mortality

Association of particulate matter with mortality has been reported widely. A possible association between heart disease mortality/morbidity and the same day particulate levels, was observed by Mazumdar and Susman (1983) in an air pollution study at Pittsburgh, USA, while no association was seen between SO₂ and mortality/morbidity. Another study (Spix et al 1993) at Erfurt, East Germany also reported that effect of particulate matter was stronger than effect of SO₂. An increase in 15 µg/m³ from 331 µg/m³ was associated with 22% increase in mortality.

Dockery et al (1992) found that total mortality increased by approximately 0.7% per 10 $\mu\text{g}/\text{m}^3$ increase in PM10 with some stronger associations for cardiovascular mortality (approximately 1.4% per 10 $\mu\text{g}/\text{m}^3$ in PM10), and considerably stronger associations for respiratory mortality (approximately 3.4% per 10 $\mu\text{g}/\text{m}^3$ in PM10). In Tennessee total mortality was found to increase by 16% for each 100 $\mu\text{g}/\text{m}^3$ increase in PM10 (Dockery and Pope 1994). In central Europe a 3.8% increase in mortality in association with 100 $\mu\text{g}/\text{m}^3$ TSP (lagged 2 days) for a time period 1982-1994 was detected by Peters et al (2000). When the TSP is dominated by 68% of PM 10 it is associated with 9.5% increase in mortality (CI 1.2-18.5%).

At Phoenix, USA, Mar et al (2000) found association between mortality and PM of varying diameters (PM 10, PM 2.5, PM 10 minus PM 2.5). Total mortality was significantly associated with CO and NO₂ and weakly associated with SO₂, PM 10, PM 2.5, PM 10 minus PM 2.5. Cardiovascular mortality was significantly associated with CO, NO₂, SO₂, PM 10, PM 2.5, PM 10 minus PM 2.5. Recently, Samoli et al (2002) reported that an increase in black smoke by 50 $\mu\text{g}/\text{m}^3$ was associated with 2.2% and 3.1% increase in mortality, when the analysis was restricted to days <200 $\mu\text{g}/\text{m}^3$ and < 150 $\mu\text{g}/\text{m}^3$ respectively in eight western and five central-eastern European countries. In Hongkong, Wong et al (2002) observed significant effects of PM 10 for respiratory mortality.

An overall post neonatal mortality rate of 3.1, 3.5, and 3.7 were observed among the infants exposed to low, medium and high levels of PM 10 respectively in USA (Woodruff et al 1997). In normal birth weight infants, high PM 10 was associated with respiratory causes and sudden infant death syndrome. One of the recent outcome reporting

associations between day-to-day particulate air pollution and increased risk of various adverse health effects including cardiopulmonary mortality is a study by Pope III et al (2002). In this study authors report that each 10- $\mu\text{g}/\text{m}^3$ elevation in fine particulate air pollution was associated with approximately a 4%, 6%, and 8% increased risk of all-cause, cardiopulmonary, and lung cancer mortality, respectively. While coarse particle fraction and total suspended particles were not consistently associated with vital status and cause of death data.

9.2.3.2 Respiratory problems/ morbidity

PM 2.5 and PM 10 has significant effect on admission rates for a subset of respiratory diagnoses (asthma, bronchitis, chronic obstructive pulmonary disease, pneumonia, upper respiratory and lower respiratory tract infections), with a relative risk of 1.24 for a \log_{10} increase in exposure (Buckeridge et al 2002). Dockery and Pope (1992) found statistically significant negative association between peak expiratory flow and PM 10 in Utah valley during 1990-91. For a 10 $\mu\text{g}/\text{m}^3$ rise in PM10, respiratory hospital admissions increased by approximately 1.1%, for Chronic Obstructive Pulmonary Disease (COPD) admissions by 2.4%, congestive heart failure by 1.0%, coronary heart disease by 0.6%, asthma by 1%, lower respiratory symptoms by 3%, cough by 3%. Several such other respiratory disorders were also found correlating with 10 $\mu\text{g}/\text{m}^3$ increase in PM10.

In Toronto, Canada during 1984-1994, an increase of 10 $\mu\text{g}/\text{m}^3$ in PM 10, PM 2.5 and PM 10-2.5 were associated with 1.9%, 3.3% and 2.9% respective increase in cardiac hospital admissions. After controlling the association for gaseous pollutants, the percentage reduced to 0.5%, 0.75% and 0.77% respectively in hospital admissions (Burnett and Brook 1999).

PM 10 and PM 2.5 significantly related with increase in respiratory related emergency visit (REV) in Santiago, Chile (Ilabaca et al 1999). During cold months an increase in $45 \mu\text{g}/\text{m}^3$ in the PM 2.5 was related to a 2.7% increase in the number of with a two-day lag, to an increase of 6.7% in the number of visits for pneumonia with a three day lag.

Significant positive association between emergency hospital admissions for respiratory diseases and PM during 1992-94 was found in London (Atkinson and Leon 1999). In all age group PM 10 associated with admissions for respiratory diseases 2.98% particularly strong in children 4.85%. Similarly strong associations were observed for PM 10 with increase in elderly for COPD and asthma. For other lower respiratory infections and cardiovascular diseases associations were found between various air pollutants.

In winter even low-level pollution aggravates the respiratory health of asthmatic adults with mild or moderate asthma (Neukirch and Korobaeff 1998). In San Diego, higher traffic flows were related with increase in repeated medical visits for asthmatic children in a low-income population, California. Traffic exhaust aggravated asthmatic symptoms in individuals already diagnosed with asthma (English et al 1999). In most sensitive asthmatic individuals biological significance may occur at particulate concentrations below $100 \mu\text{g}/\text{m}^3$ (Hext 1999).

A recent study by Creason et al (2001) found that PM 2.5 is associated with a diminished heart rate variability (HRV) response in the elderly. The results of the study also suggested that decrease in HRV with higher concentrations of PM 2.5 might be a consequence of greater loss of parasympathetic control of heart rate.

9.2.4 Indian scenario

Lahiri et al (2000) in a study on exposure effect of air pollution in Calcutta, detected remarkable increase in alveolar macrophages in the sputum of the urban residents (22.7/high power fields (hpf)), than that of the rural controls (2.8/hpf, $p < 0.0001$). Inflammatory cells like neutrophils and eosinophils were also found increased in city residents. The authors opined that exposure to severe air pollution as possible reason for the findings. According to Down to Earth (1997b), nearly 52,000 people died prematurely in 36 Indian cities due to high levels of SPM in 1995, a rise of 28% compared to 40,000 in 1991-1992. The number of sickness requiring medical assistance and hospital admissions in these cities due to elevated levels of SPM is estimated to have increased from 19 million in 1991 to 25 million in 1995. In Kolkata and Delhi, cases of hospital admissions and sickness requiring medical treatment suspected to have caused by air pollution doubled in the span of three years crossing 5 million mark in 1995. Another study opined that in 33 Indian cities ambient SPM is the main cause for steady increase in premature deaths and sickness among the people (Table 9.1). Health costs estimated to have caused due to due to air pollution is alarming (Table 9.2).

The premature deaths in Calcutta during 1991-92 were 5726, while within a span 3 years it almost doubled to 10647. Such sharp increase were also noticed in other metropolitan cities like Mumbai and Delhi, where the premature deaths during 1991-92 was 4477 and 7491 respectively, which rose to 7023 and 9859 in 1995. Shah and Nagpal (1997) also provides statistics of air pollution related health impacts in Mumbai, the following are incidence of air pollution related health impacts and cost estimates (Table 9.3).

Table 9.1 Estimates of health effects due to air pollution

Total	Premature death		Number of sick cases	
	1991 – 92	1995	1991 – 92	1995
33 cities	40351	51779	19,098,127	25,645,721

Source: <http://www.iglindia.com/whyigl/humans1>

Table 9.2 Health costs due to air pollution in Indian cities

Health costs due to air pollution in Indian cities		
Nature Of Effect	Number	Cost valuation (US \$ millions)
Premature deaths	40,351	170 - 1,615
Hospital admissions and sickness requiring medical treatment	19,800,000	25 – 50
Minor sickness (including restricted activity days and respiratory symptom days)	1,201,300,000	322 – 437
Total		517 - 2,102

Source: <http://www.iglindia.com/whyigl/humans1>

Table 9.3 Air pollution related health impacts in Mumbai

Health Impact	Number of cases	Total cost (Rs in millions)
Mortality	2765	691
Emergency room visit	76000	22
Bronchitis (Children)	190000	61
Asthma attacks	741000	741
Respiratory symptom day	60 million	1189
Respiratory admissions	4000	38
Restricted activity days	19 million	523

Source: Shah and Nagpal (1997)

In the city of Bangalore, respiratory problems among children have risen threefold during the last 20 years (Paramesh and Cherian 2001). The incidence of respiratory ailments such as asthma during 1979, was only nine percent in the child population of the district. By 1999, it had risen to 29.5 percent (Table 9.4). Corresponding increase in number of industries and automobiles were also witnessed. Globally, over 180,000 people die from

asthma each year. India has approximately 15-20 million asthmatics and the prevalence and incidence is more amongst the affluent (Narain 2002)

Table 9.4 Asthma cases in Bangalore

Year	Percentage of asthma cases	Number of Industries	Number of automobiles (in millions)
1979	9	4700	0.146
1984	10.5	7887	0.236
1989	18.5	14384	0.460
1994	24.5	25758	0.715
1999	29.5	40146	1.223
Source: Paramesh and Cherian 2001			

Another recent health survey conducted in urban India during 1998-99 revealed shocking state of urban health (Adrian Kennedy - personal communication). Almost 100% of the respondents had some medical problem and 40% were on daily medication, 50% were physically unfit, 35% over weight, 72% had high levels of stress, 50% had multiple cardiac risk factors, 37% were at risk of cancer, 26% had headaches and 10.89 had respiratory disorders. About 69%, 57.45%, 61.2% and 80% people were recorded for high cardiac risk in Delhi, Jamshedpur, Mumbai and Hyderabad respectively. In Coimbatore, K G hospital, during 1999 health scan among the visitors for various ailments about 83.4% were recorded for primary cardiac risk, 16% for secondary cardiac risk and 3.12% for existing heart problem. Apart from the scarce unpublished data, in Coimbatore current trend of respiratory sickness among the people is largely unknown. Verbal inquiries with physicians in Coimbatore however hinted that large number of people suffer from respiratory ailments here.

9.3 Methodology

In the current study an attempt is made to know the state of respiratory problems that are prevalent among the residents of Coimbatore. Since the respiratory survey was envisaged

as a small part of the study, a detailed examination of air pollution associated respiratory problem could not be conducted due to time and logistic constraints. In Coimbatore city, there are about 20 large private hospitals having about 2000 beds (Prasad 2002). The Coimbatore Medical College hospital (CMC) run by state government has 1200 beds. Employees State Insurance hospitals run by the government has 800 beds. Apart from that there are several medium sized hospitals that handle outpatients and inpatients. Numerous private dispensaries and clinics are also present. All put together, the total beds in urban and suburban Coimbatore contains nearly 7000 beds. In almost all these hospitals morbidity records of patients are not maintained. Instead the records are handed over to the patients. In one or two hospitals brief inpatient records although maintained, is not in a proper and useful format. A careful observation of the available hardcopy in those private hospitals raised number of other difficulties in gleaning useful information. One main problem in all private hospital records is that they fail to collect personal and background information such as occupational details, history of the disease, environmental background etc. Although many medical practitioners are aware of air pollution associated respiratory disorders, they rarely give attention to issues of environmental epidemiology and hence it appeared tough to extract data on morbidity from private sector hospital records. Apart from the private hospitals and clinic, several attempts were made to obtain morbidity and mortality data from the CMC, ESI, but the authorities declined to share the data for certain official seasons.

About 12 other small dispensaries maintained by the city corporation authority, without inpatient facility are also present in Coimbatore. In suburban areas and villages, health department of the state government runs such dispensaries. After a series of discussions with the authorities, they permitted to collect the data from these hospitals. The cost of the treatment is either free or minimal in all of the above said hospitals and only people

from lower economic strata consult these health centers. Hence data collected from these centers would represent health status of the economically weaker section and low-income group people and a few government employees. Morbidity data in corporation dispensaries and public health centers is daily recorded in a simple format. Most of the clerical staffs to ease their workload record neither gender breakup nor disease details. Reliability of data in these health centers depends highly upon the staff recording the data and maintaining the records. Moreover the recording pattern also had discrepancies between hospitals. The number of people visiting the corporation dispensaries also vary greatly according to the confidence public hold on the doctor. Despite all the drawbacks, hard copy data form various corporation dispensaries and primary health centers that fall within the suburban area of Coimbatore were collected in available format.

To collect the basic respiratory health status of the people, a questionnaire (Appendix 3) was developed and circulated among 1200 people residing in various urban, suburban and rural environments of Coimbatore. Since the preliminary survey showed that respondents hesitated to share certain personal information such as smoking habits and information of their economic status, such questions are avoided though they are significant to the study. Some of the respondents were also found reluctant to disclose long-term respiratory diseases they are suffering from. No particular effort was made to conduct the survey in the context of occupational profile due to certain constraints. Instead the questionnaire was circulated randomly. Although many cases were interviewed personally, most questionnaires were circulated among teachers, students, employees, and business people within the city.

9.4 Results

9.4.1 Questionnaire survey

Though 1200 questionnaires were distributed, data could be obtained only from 635. Among 635 respondents 53% suffer from the respiratory disorders and other associated respiratory system ailments (Figure 9.2). Among the 443 male respondents 236 individuals are affected by the respiratory problems. Among 192 female respondents 103 suffer respiratory and related disorders. However, people suffering from serious respiratory ailments (bronchial asthma, sinus problems) are only 13 % compared to certain ailments such as headache, cough and nose block. Table 9.5 and 9.6 gives detail picture of male and female respondents respectively, who are suffering multiple diseases. Following paragraphs explains the disease scenario of male and female respondents including other background details.

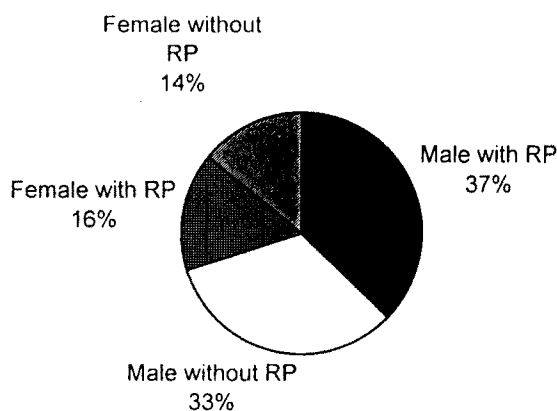


Figure 9.2. State of respiratory health among the respondents for health survey (RP = Respiratory Problems).

Table 9.5 Status depicting number of male respondents having multiple respiratory disorders

<u>Male with Resp Problems</u>	Asthma/wheezing	Runny nose	Nose Block	Cough-allergic/Nocturnal	Sneezing/Dust allergy	Sinusitis	Headache
Asthma/wheezing	58	14	10	18	9	5	17
Runny nose		58	22	26	32	8	12
Nose Block			57	19	23	12	18
Cough-allergic/nocturnal				89	26	8	30
Sneezing/dust allergy					72	9	23
Sinus						25	6
Headache							89

9.4.1.1 Males with respiratory problems (MRP)

Among 443 total males, individuals who suffer from respiratory disorders are referred hereafter as MRP. About 95% of them reside in urban, suburban and industrial areas, while rest 5% are rural. Among MRP, 29% are engaged in trade, 5% drivers, 27 % employed in government/private firms. 32% were labors most of who are working on daily wage basis. The rest of the samples were students and teachers. Two wheelers are the mode of conveyance for 32%, while 23% travel by bus, 20% by cycle and 7% by 4-wheelers (car). About 25% of the people had symptoms of bronchial asthma. Of this 25%, 67% developed the disease within 5 years. Asthma is most prevalent among the age group 45 – 70 age group. 62% of them experience the problem severely in winter while 17% in rainy season. Among the 26% of MRP who suffer running nose, (84%) had picked up the disease within the last 5 years. Running nose was noticed in 25% of MRP and it is prevalent among all age group (20-70 years). 76% of people with running nose experience its high intensity in winter and rainy season.

Among 57 individuals suffering from nose block, 70% got the problem five years ago. It is most common among the age group 41-45 years and 45-50 years, followed by 20-25

years. About 48% recorded severe nose block in winter and rainy season, while 28% in winter alone. Cough (all kinds, such as allergic cough, dry cough, and nocturnal cough) is experienced by 37% of the male in MRP list of which about 40% are suffering for more than 5 years. Cough is common among all age group.

Sneezing in the presence of high dust or in polluted environment is a common problem among the respondents. About 71 individuals of MRP suffer from this problem and within this group 67% developed it 2 to 5 years ago. Sneezing among those suffering from it is observed high during winter and rainy seasons (68%). Sneezing is found highest among the 36-40 years age group. Sinusitis, another respiratory disorder that is believed to be associated with air pollution is noticed among 10% of MRP, with highest number in the 46-50 years age group. In the case of sinus problems about 90% of the affected group are suffering for more than 5 years. About 50% of them happen to be either occupationally or residentially associated with textile industry while the rest live near garbage dumping sites. Most of them (60%) are severely affected during winter season.

Headache, although is found to be symptom for many other disorders including infectious diseases, was included in the questionnaire since headache is also associated with sinus problems. In the current survey 37% of MRP are victims of headache. Of those 41% are suffering for more than 5 years, while the rest developed it recently. Unlike other respiratory disorders the people with headache problems experience the severity in summer (31%), 27% in summer and winter and 27% in winter and rainy seasons. Headache is found common among all age group.

9.4.1.2 Females with respiratory problems (FRP)

Among the 103 females individuals who are identified as FRP, 62% live in urban/city

environment, 30% in suburban and 12% in rural areas. About 30% of FRP are employed in private/government sectors, 18% housewives, 13% labors of daily/weekly wages and 26% teachers. Almost 78% of respondents are residents of Coimbatore for more than 10 years. Only 10% of the FRP happened to have their residence in remote locality far away from highways, while rest 90% reside near national highways, state highways and city/commercial roads within the city. About 19% of FRP reside close to textile mills (1km aerial distance), 4% close to foundries, 11% near textile and foundries and 28% near garbage dumping sites, 6% of FRP resided in areas with no such activities, 15% other activities like plastic industries and engineering industries. 18% of FRP have no idea of any such activities going around near their houses. For about 40% of the FRP, common mode of travel is bus, while 21% travel by two-wheeler and 13% by cars.

Table 9.6 Status depicting number of female respondents having multiple respiratory disorders

<u>FEMALE</u>	Asthma/ Wheezing	Running nose	Nose Block	Cough- allergic/ nocturnal	Sneezing/ dust allergy	Sinus	Headache
Asthma/wheezing	26	4	6	1	5	1	5
Runny nose		13	5	6	5	0	3
Nose Block			14	6	8	0	6
Cough- allergic/nocturnal				26	13	0	10
Sneezing/dust allergy					39	4	9
Sinus						13	3
Headache							39

About 25% of FRP are affected by bronchial asthma/wheezing, of which most (75%) suffer severely in winter and rainy season. Half of the asthmatic patients are residents of Coimbatore city while rest live in suburban environments. About 60% of them developed disease 5 years ago. Higher number of asthma cases is observed among the above 40 years age group.

During rainy season and winter about 12% of FRP suffer from running nose. Within this 12%, running nose is prevalent (90%) in city dwellers, whose work place lie close to highway or commercial roads in the city. In almost all cases either textile mills or garbage burning site is present in the close vicinity of their residence.

Similarly about 13% of FRP are victims of nose block of which 90% developed it within the last 2-5 years. It is prominent among the age group 25-30. All of them feel the problem severely in winter and rainy seasons, though they experience it mildly throughout the year. Except two all other 14 individuals belong to urban and sub-urban environment. Five of them also suffer from bronchial asthma. Cough, sneezing and headache are the most common disorders occurring in 25%, 37% and 37% of FRP respectively. Cough and sneezing are observed severe for 75% of the people in winter and monsoon season. Cough and sneezing are highly prevalent among the age group 25-30 years and 35-40 years respectively.

9.4.1.3 Background status of respondents without respiratory problems

Male without respiratory problems (MWRP)

Among the total male respondents 47% of them are free from any respiratory problems mentioned in the questionnaire. 54%, 33% and 13% of them belong to urban, suburban and rural areas respectively. About 68% of the people who do not suffer from any such problems are living in their respective locality for more than 10 years. A majority of them (60%) reside in places where busy highway or city/commercial centers are not present in their residential vicinity. If occupationally classified 35% are engaged in trade, 36% are employed /salaried, 18% are labors, rest students and retired. Nearly 60% of them are associated with roadside shops/offices, while 12% were textile and foundry workers

respectively. Only 33% of MWRP. workplace is found near national/state highway and for another 34% workplace is near either village roads/roads with low traffic.

Female without respiratory problems (FWRP)

Among the females who do not suffer from respiratory problems (89 individuals), 55% are urban, 28% are suburban and 17% are rural residents. Around 51% of them are living in their respective locality for more than 10 years, while 30% are inhabitants only for 5 years. Occupational classification showed 3% are engaged in business, 51% - employees/salaried, 13% - housewife, 6% - labors, 28% - student. Only 6% of people have their residences close to national highway, while 25% have it near state highway, 20% near city/commercial roads and rest 18% near village roads with very low traffic. Mode of travel of 45% of them is bus and 23% by two-wheeler and rest by walk or public bus.

9.4.2 Hospital data

Data collected from the Coimbatore Corporation dispensaries for the period January 1999 – December 2000 are shown in the Figures 9.3 to 9.8. The charts show only the monthly record on number of individuals who visit for respiratory problems. Working time for these dispensaries is 7-10 AM and 2-4 PM. Except in few dispensaries, the record on new and old cases are not differentiated. Visits made by the old cases are recorded even in the absence of doctor if they are suffering from chronic problem and come to collect medicines as prescheduled. The following passages explain the details of data of each dispensary.

- The dispensary at Ramalingam colony is present in a residential area where most of the residents of the place are of high-income group. As mentioned earlier economically poor people from close by areas to Ramalingam colony visit the health

centers for the ailments. This dispensary is located at a distance of 3-km from the station C (details in Chapter 2) that recorded the RSPM levels below permissible limit. On an average about 2338 old and new cases visit monthly to the dispensary. Among this only 5% visit for respiratory problems (Figure 9.3). Higher number of visits recorded for Upper Respiratory Infection (URI) and Lower Respiratory Infection (LRI) are during the months of October - March for both the years. No distinguishing pattern is observed for asthma and other respiratory problems. A positive correlation was obtained among the number of monthly visitors for LRI, URI and RSPM values of the nearest air sampling station (Figure 9.10 and 9.11).

- Thirumal Street dispensary is present near station A in a thickly populated area within city. During the period January 1999 – December 2000, average of 1995 (1163 old cases and 832 new cases) people visit monthly to the hospital for various ailments. The recorded visits for respiratory ailments averaged around 306/month with an average of 30 persons per month for asthma (Figure 9.4). No trend was observed between seasons or months.
- Ramnathapuram dispensary is located in a residential cum commercial area at about 6 km from air sampling station A. In this dispensary, visits for respiratory ailments are recorded without any break up for URI, LRI and Asthma. Average of 3960 individuals visit monthly of which 30% are for respiratory disorders (Figure 9.5). Apart from that about 300 visits/month was recorded for ENT diseases that includes sinusitis.
- Gandhipuram dispensary is located close to air sampling station B (1km). Number of visitors to this hospital is very less (average of 754 per month), probably because the area is dominated by high-income group people. Among the visitors, almost half of them (49%) have recorded respiratory ailments (Figure 9.6). During months of

November more visits for asthma are recorded. A positive correlation was obtained among the number of monthly visitors for LRI and RSPM values of the nearest air sampling station (Figure 9.9). Apart from that no notable changes are recorded. The area also recorded comparatively high concentration of RSPM ($84.4 \mu\text{g}/\text{m}^3$) in our study.

- Ukkadam dispensary is located in thickly populated market area that is mixed with few slum settlements. This area is located at the edge of city corporation limits. Towards south and south west of Ukkadam, wetlands and agriculture dominate large piece of land. Hence the visitors to the dispensary will be only a very few local population. On an average about 2484 individuals visit monthly for various ailments of which 16.7 % are for respiratory disorders including bronchial asthma (Figure 9.7). Except for URI, the visitors for LRI and asthma did not show any distinctive seasonal pattern.
- Poomarket area dispensary is only visited by very low number of people (average of 1293 individuals/month). About 17% of the visitors are for respiratory problems (Figure 9.8). Higher numbers of visitors are noticed for asthma during winter and rainy months.

Figures 9.3 – 9.8 Monthly record of people visiting for various ailments at various places

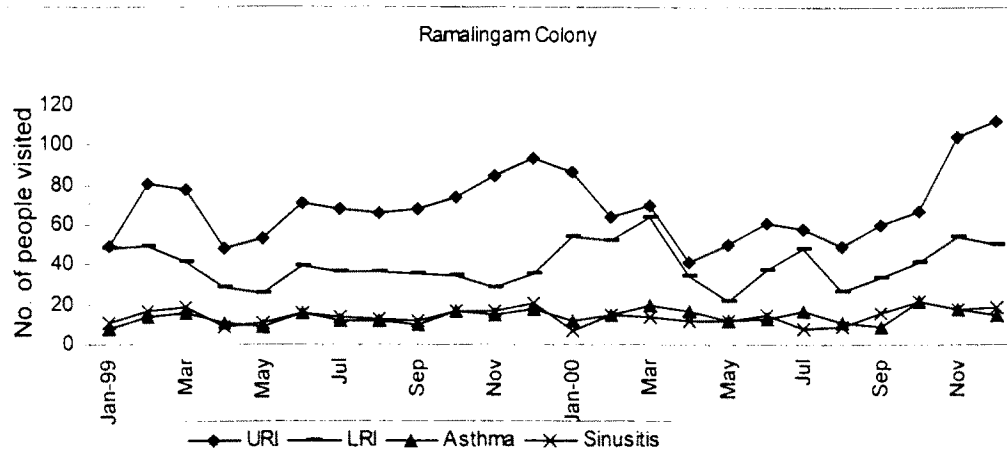


Figure 9.3 Monthly record of outpatient visits at Ramalingam colony dispensary

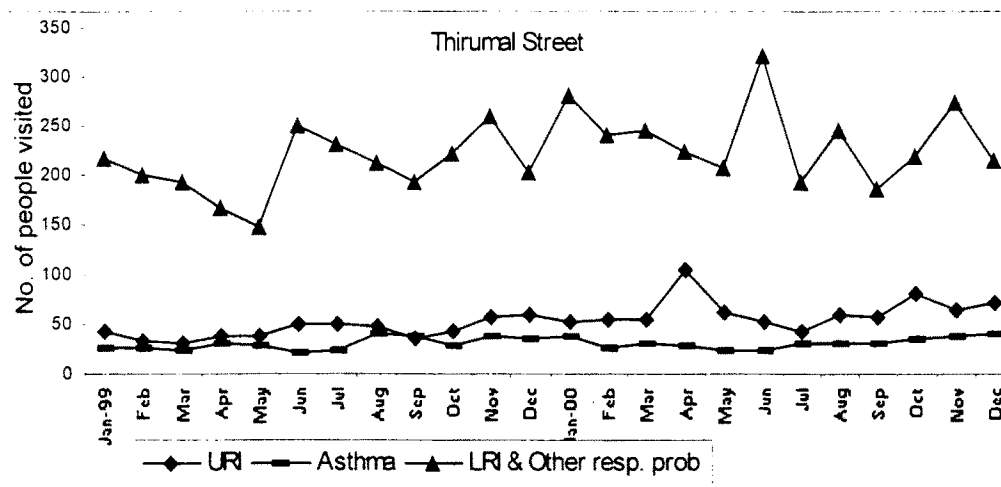


Figure 9.4 Monthly record of outpatient visits at Thirumal street dispensary

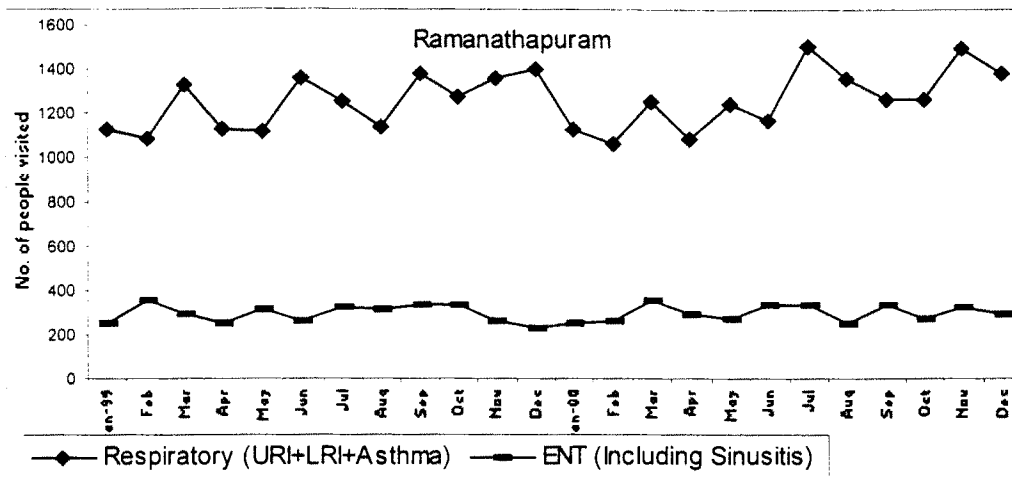


Figure 9.5 Monthly record of outpatient visits at Ramanathapuram dispensary

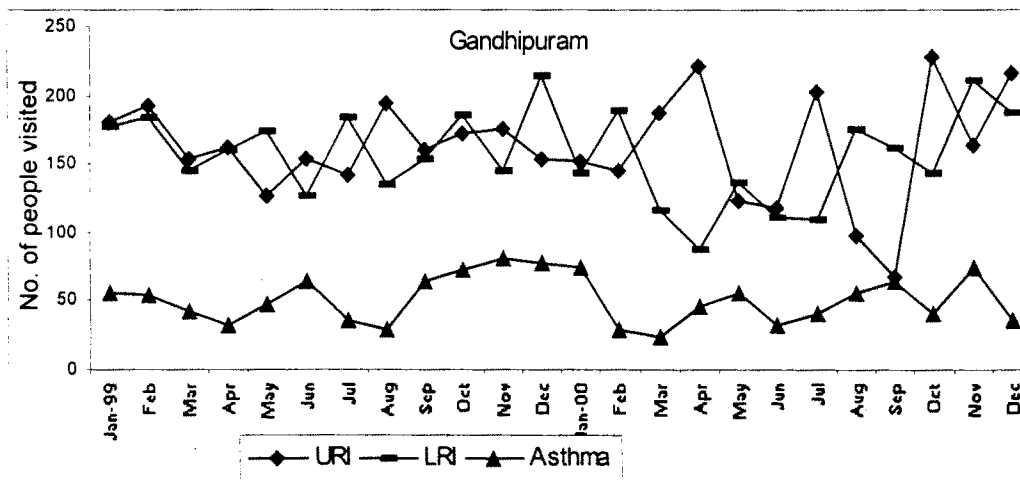


Figure 9.6 Monthly record of outpatient visits at Gandhipuram dispensary

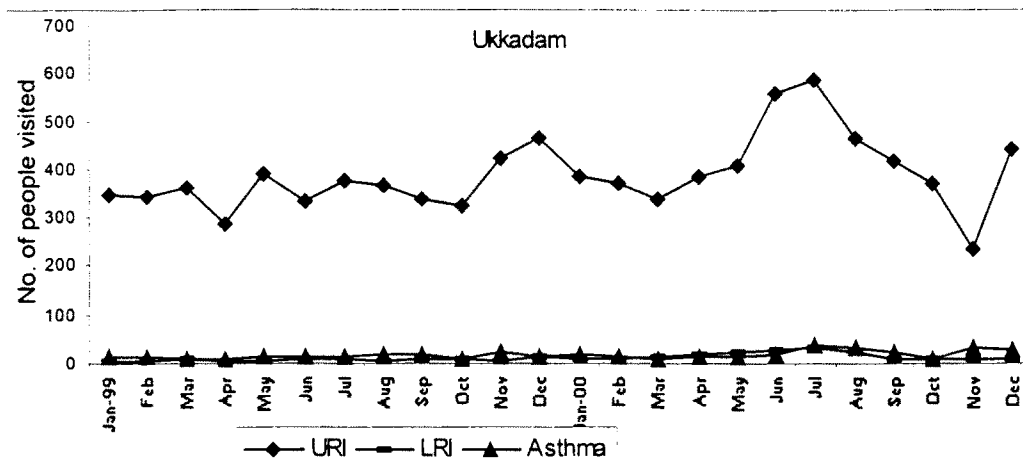


Figure 9.7 Monthly record of outpatient visits at Ukkadam dispensary

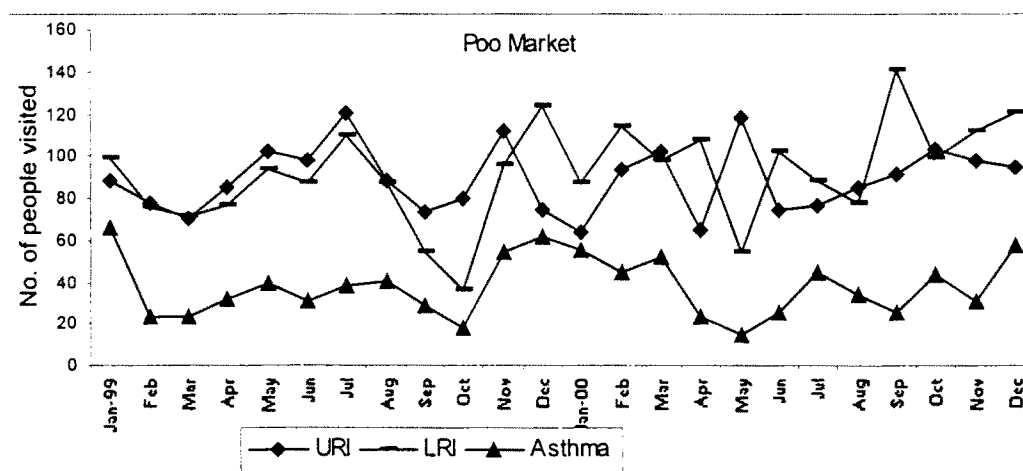


Figure 9.8 Monthly record of outpatient visits at Poomarket dispensary

9.5 Discussion

Among males and females suffering from respiratory problems about 60% and 62% live in urban/city environment, 33% and 30% in sub-urban areas respectively. Among the respondents who do not have respiratory problems, rural residents seems to be slightly higher (15%), indicating the urban environment as one of the possible reason for respiratory disorders. Among the males suffering from respiratory diseases, a majority of them (80%), were associated with roadside shops, textiles and foundry, while those respondents who do not suffer from respiratory problems, percentage in above work place category is 65%. Such differences need further study to establish whether air pollution could be a possible contributing factor for respiratory diseases.

Majority of the people who suffer from respiratory ailments experience its intensity during winter or winter and rainy season. During winter months, RSPM values are also observed higher in the study (Chapter 5) suggesting that it may have a role in respiratory disorders or aggravation of respiratory problems among the residents. About 60% respondents who developed respiratory disorders within the period of 1995-2001 suggest a positive relation with increase in vehicular pollution that has been sharply increasing since 1992. Number of visitors for respiratory disorders during the months of winter and post monsoon in some dispensaries indicates to a possible role of airborne particulate matter. A positive correlation was noted between the RSPM values and number of visitors for respiratory problems in certain dispensaries (Figures 9.9 – 9.11).

In India, despite high levels of air pollution and health risks caused by these air pollutants, understanding about nature of the air pollution associated diseases are very

scarce. A recent Indian Council of Medical Research (ICMR) Study shows that medical colleges have very low rates of publication e.g. 20% of the 156 medical colleges had not published a single research paper during 1990-1994. In addition those who did publish managed to do so in low impact journals (Sen 2002). In seven years (November 1987 – December 1994), Indian researchers had published only 19952 items in 1440 journals. Of these 19,916 were journal articles (as classified by Medline), nine were letters and eight clinical trials (Arunachalam 1997). Nearly three-fourths of these articles (14,822) were published in journals whose impact factor less than 1. Only 58 papers were published in journals whose impact factor was higher than 8. Indian researchers have used just one epidemiology journal to publish two papers.

This would reflect the quality and quantity of research and development in medical science. The state of basic medical science research being the condition, environmental epidemiological research is further dismal. A brief search in Indian journals and magazines yielded no article elaborating a cohort study or personal exposure study related to air pollution. As discussed earlier, lack of R&D in medical research especially in the field of environmental epidemiology is a discouraging factor in India. Steps are essential to streamline recording the morbidity in a more detailed fashion. All private hospitals and medical practitioners need to be aware of the valuable knowledge that can be generated from such records. Data should be made easily available to the research community by publishing in internet or statistical documents in public domain. Such a reform would give great impetus to studies on air pollution and health in a developing tropical country such as India.

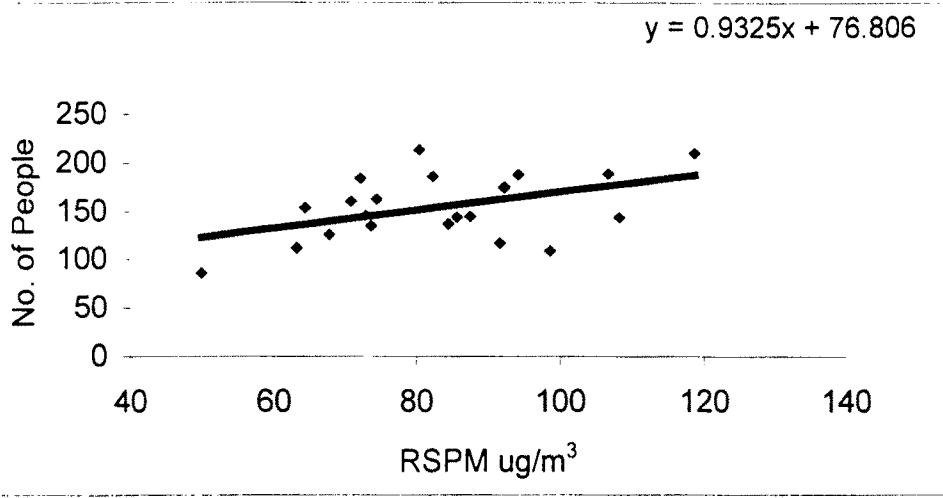


Figure 9.9 Regression analysis between hospital visits for LRI in Gandhipuram (Near Station B) and RSPM values

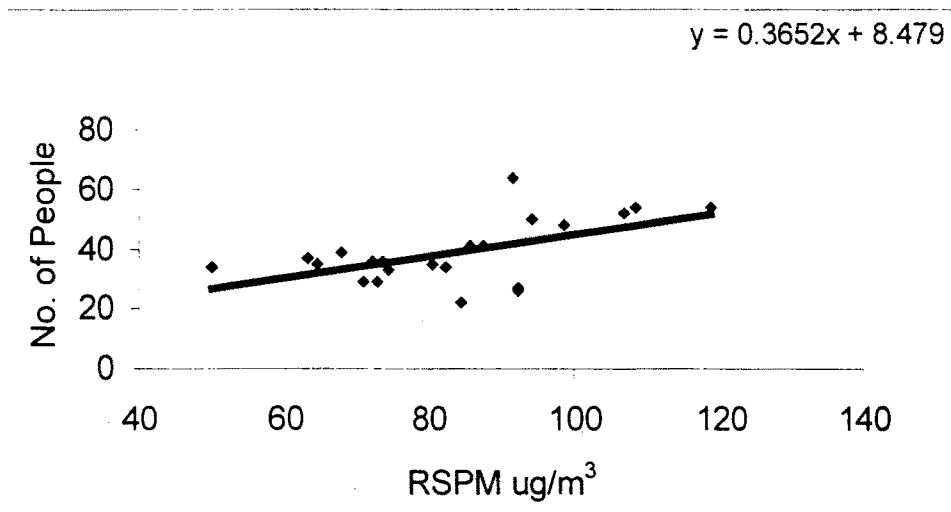


Figure 9.10 Regression analysis between hospital visits for LRI in Ramalingam colony (Near Station B) and RSPM values

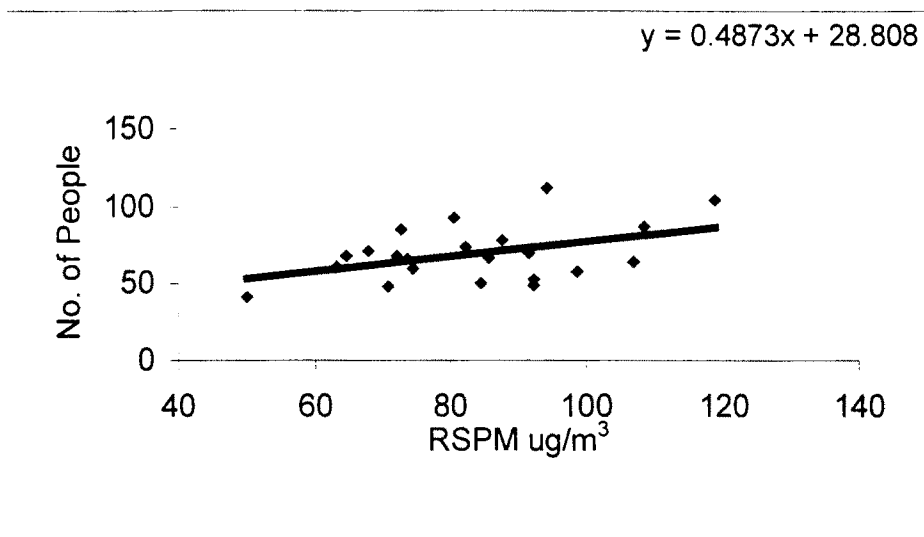


Figure 9.11 Regression analysis between hospital visits for URI in Ramalingam colony (Near Station B) and RSPM values

9.6 Summary and conclusion

A preliminary attempt was made to know the status of respiratory disorders among the people residing in Coimbatore through a preliminary questionnaire survey and hospital records. Among 635 respondents of questionnaire survey 53% suffer from the respiratory disorders and other respiratory system associated ailments. Nearly 90% of the people who are suffering from respiratory problems live in urban, suburban or industrial environment. A substantial percentage of respondents with respiratory problems seem to be associated with roadside shops. In certain dispensaries number of hospital visits made by people for respiratory problems showed positive correlation with RSPM values.

In India, lack of studies especially in the field of environmental epidemiology is a discouraging factor. Immediate measures are essential to streamline recording the morbidity in a more detailed fashion. Data should be made easily available to the research community by publishing in internet or statistical documents in public domain. Such a reform would give great impetus to studies on air pollution and health

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Appendix 1 Air quality in certain cities of India

Cities		Population of urban agglomeration	Year	SPM level ($\mu\text{g}/\text{m}^3$)		
				Minimum	Average	Maximum
Metropolitan	Mumbai	16368084	199-1995	48.5	225.7	573
Metropolitan	Kolkata	13216546	1990-1995	31.5	353.6	1278
Metropolitan	Delhi	12791458	1987-1995	62.5	404	1609
Metropolitan	Chennai	6424624	1987-1995	26.2	122.3	516.1
State capital city	Bangalore	5686844	1988-1991	18.5	146	632
State capital city	Hyderabad	5533640	1990-1995	20.6	150.4	582.5
State capital city	Ahmedabad	4519278	1989-1995	37.5	252.5	939
Class II city	Pune	3755525	1987 - 1995	50	202	533
State capital city	Jaipur	2324319	1990 - 1995	37	278	1067
State capital city	Lucknow	2266933	1992- 1995	224.7	374.5	535
State capital city	Trivandrum	<1300000	1991-1995	24.4	107.8	317.2
Class II city	Shimla	<1300000	1987- 1995	18.8	197.5	666
Class II city	Coimbatore	1446034	1993-1995	10	50	153
Class II city	Cochin	1355406	1988-1995	10.5	97.15	363.2

Source: Agarwal and Narain (1999)

Appendix 2 Air quality Standards

Central Pollution Control Board (CPCB 2000) Air Quality Standards (India)

Ambient Air Quality Standards (National). Concentration in ambient air ($\mu\text{g}/\text{m}^3$)				
Pollutant	Time weighed average	Industrial	Residential, Rural & other areas	Sensitive Areas
Suspended Particulate Matter (SPM)	Annual Average	360	140	70
	24-hours	500	200	100
Respirable Suspended Particulate Matter (RSPM)	Annual Average	120	60	50
	24-hours	150	100	75
Lead (Pb)	Annual Average	1.0	0.75	0.50
	24-hours	1.5	1.0	0.75

US EPA Standards (1997)

PM 10	
Annual arithmetic mean	$50 \mu\text{g}/\text{m}^3$
24-hour Average	$150 \mu\text{g}/\text{m}^3$
Lead – quarterly average	$1.5 \mu\text{g}/\text{m}^3$
Web 19 (http://www.epa.gov/)	

Abbreviations

- BaP : Benzo(a)pyrene
- COPD : Chronic Obstructive Pulmonary Disease
- FRP : Females with Respiratory Problems
- FWRP : Females without Respiratory Problems
- HIG : High Income Group
- IPHM : Integrated Programme on Heavy Metal Pollution (Indian study)
- LRI : Lower respiratory tract infection
- MRP : Males with Respiratory Problems
- MWRP : Males without Respiratory Problems
- PAH : Poly Aromatic Hydrocarbons
- PM 10 : Particulate Matter of Aerodynamic size below 10 microns
- PM 2.5 : Particulate Matter of Aerodynamic size below 2.5 microns
- RSPM : Non Respirable Suspended Particulate Matter
- RSPM : Respirable Suspended Particulate Matter
- SIDCO : Small Scale Industrial Development Corporation
- SPM : Suspended Particulate Matter
- TSPM : Total Suspended Particulate Matter
- URI : Upper respiratory tract infection

